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The Future of Physics, Past and Present*

KARL K. DARROW
Bell Telephone Laboratories, New York, New York

THE time will infallibly come when the Richtmyer lecture will perforce be delivered by people who do not remember Richtmyer, and until it does come we who remember him should try to revive his image. To my regret I can do this only a little, for I never enjoyed with him the intimacy either of colleague or student. I sat with him in numberless committee meetings, and learned to appreciate his breadth and scope, his value in deliberation and decision, his fabulous capacity for work. His range as a physicist will be attested by his *Introduction to Modern Physics*, and his depth by the researches which he made or caused to be made on x-rays. Just at the present time there is a way of characterizing him that I think is very apt. He was a man who, had he been spared, would have been asked at an early date to take a very high place in the organization of physics to serve the war effort, and would have done it admirably well. He deserves a greater share of this address; but as I cannot adequately give it, I turn now to what has been described as an "enigmatic" topic.

In the economic world good times have followed on bad and bad upon good for a great many years, in the recurrent though uneven cycle of prosperity and depression. In the phases of depression there often springs up the idea that the depression is doomed to be permanent, because invention and discovery have reached their uttermost limits, new things are no more to be hoped for, enterprise is vain, and all that remains to be done is to divide what we have. This idea, which President Wriston of Brown University has called "the fallacy of the mature economy," returns at appropriate intervals like a comet, and like a comet also it can frighten those who do not know that it has been around before. The history of its cyclic returns is interesting and instructive, but is not the topic of this discourse. My topic is supplied by the fact that the corresponding fallacy once arose in physics, and flourished for a time extending into the memories of men yet living.

One of the earliest sayings I ever encountered when I set forth on my path as a student of physics was the one which I now quote:

> While it is never safe to affirm that the future of Physical Science has no marvels in store even more astonishing than those of the past, it seems probable that most of the grand underlying principles have been firmly established, and that further advances are to be sought chiefly in the rigorous application of these principles to all the phenomena which come under our notice. It is here that the science of measurement shows its importance—where quantitative results are more to be desired than qualitative work. An eminent physicist has remarked that the future truths of Physical Science are to be looked for in the sixth place of decimals.

* The third Richtmyer Memorial Lecture of the American Association of Physics Teachers, delivered on January 15, 1944.

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I might dissimulate by saying that this passage comes from a former catalog of a famous mid-western university, or something of the sort; but many of my listeners will have recognized it already, and the rest can easily find out the college from which I came. The passage comes from the *Annual Register* of the University of Chicago, in which it was embedded annually from the beginning of the University in 1893 or thereabouts until the year 1906. I presume that Michelson wrote it; at any rate we can be sure that it appeared with his approval, which comes to the same thing. Now if Michelson had not been a great man, there would be no point in my quoting it. The point is precisely that a great physicist and a great man could believe that and did believe it, as lately as 1906. Moreover, he was not alone in this belief, and the belief was anterior to his time. For a good many years I have had a vague ambition of tracing back the history of the belief, and now at last the invitation of this Association has given the definite incentive. I have not found out all that I should like to find out about this history, and in particular I have not found out who was the eminent physicist who said that the future truths of physical science are to be looked for in the sixth place of decimals. Perhaps someone in this audience knows who he was, and if that person will instruct me, I will credit him in a footnote to the published version of this speech.[1] But in the course of this historical research I found a great deal of good reading and a number of things which seemed interesting to me, and I hope that I can make some of them seem interesting to you.

Let me begin by paying my respects to Newton. It will transpire that I surmise that Newton's achievement, in establishing the laws of mechanics and the law of gravitation, was the ultimate source of the belief that physics is nearly finished. Should we then indict Newton of having been confident that he himself had finished the task? I should not dream of indicting him myself, nor would anyone else who has read his *Opticks;* but if he were so indicted, he would be acquitted at once on the sole basis of the famous saying, "To myself I seem to have been only a boy, playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

This is one of those figures of speech that are very powerful at first impact, but do not withstand analysis well. On analyzing it, you are led to wonder why, if the ocean stands for truth, Newton was not cruising on it in a boat instead of picking up the pebbles on the beach. Perhaps some would say nowadays that he was interested in borderline phenomena; but at least it is evident that for Newton the undiscovered part of truth was a great ocean, and that he did not feel that he had shrunk it to a pond.

This quotation is of 1727, or very nearly. Let me now take you across from England to France (an easier thing then than now, alas!) and 24 years onward in time, to the publication of the great encyclopaedia which the French call *THE* encyclopaedia—*l'Encyclopédie.* This was a work of great scientific, engineering, social and even political importance, but of course I mention all that only to show that it was no insignificant work from which I am next going to quote. Neither was it an insignificant man who wrote the Preliminary Discourse and, as he says, "either wrote or looked over" all of the scientific definitions: it was, in fact, D'Alembert. Though it is irrelevant here, I cannot keep myself from quoting out of the Preliminary Discourse the earliest statement known to me of a cynical joke which to this day is creeping around in the world of science: "Great men are accused first of being wrong, and finally of being plagiarists." However, I must get on to the article on Physics, which D'Alembert either wrote or at least approved. Here we read:

> Thus far only a small number of laws has been discovered in Physics, because not much progress has been made during previous centuries in this science. It is therefore our duty to make an exact investigation of these laws as far as is possible. To this end we ought to observe with care all sorts of terrestrial bodies, then examine them, and make all the researches and remark all the details [*y faire toutes les recherches et remarques*] of which we are capable.

Certainly no pessimism here, no inkling of a hint that physics is an exhausted science! Yet this was one of the men who developed Newton's ideas the

[1] This challenge was orally accepted by several listeners just after the talk, but as yet (February 21) no reference has reached me.

fastest and furthest, during that wonderful eighteenth century in France when Clairaut, Lagrange and Laplace were competing with one another in that noble race.

Of both Clairaut and Lagrange I have seen it stated, that he lamented the fact that there was only one system of the world, and Newton had discovered it! This certainly sounds like the beginnings of pessimism in physics, and perhaps it was; but in view of the fact that Laplace used the term "system of the world" (*Système du Monde*) to describe the motions of the planetary system, I am inclined to guess that Clairaut or Lagrange, whichever it was, was making a true statement about celestial mechanics rather than a false one about physics. I thought I might be able to convict Laplace of starting the wave of discouragement, in view of the celebrated saying, "to an intelligence knowing all the forces of Nature and the situations of all natural bodies at a given instant, and vast enough to subject all these data to analysis, nothing would be uncertain and both past and future would be present to its eyes."[2] Laplace, like Newton before him, was perfectly well aware that there are other forces in Nature than gravitation and other laws of force than that of the inverse square, not all of which were known. How indeed could anyone think the contrary of the man who developed the theory of capillarity? Then also there are the words given apparently on good authority as the last ever spoken by Laplace: "What we know is but little, what we do not know is immense."

I therefore acquit Laplace, and the others who developed the Newtonian mechanics, and Newton himself, of starting the phase of depression; and now I proceed to the first emergence of this phase in print, or as I should say, the first which I have traced. This occurs in a speech by Maxwell, who did *not* believe in the doctrine which he cites. Not wishing to darken his prestige in your minds for even a moment, I have told you that in my words before letting him say it in his. Now here speaks Maxwell, inaugurating the Cavendish laboratory and his own professorship in 1871:

> The opinion seems to have got abroad, that in a few years all of the great physical constants will have been approximately estimated, and that the only occupation which will then be left to physicists will be to carry on these measurements to another place of decimals. If this is really the state of affairs to which we are approaching, our Laboratory may perhaps become celebrated as a place of conscientious labour and consummate skill, but it will be out of place in the University, and ought rather to be classed with the other great workshops of our country, where equal ability is devoted to more useful ends.

Next I want to quote another authority, not so great a man as Maxwell perhaps, but a great man and one who was much more widely traveled among laboratories than Maxwell was. This was Arthur Schuster, who was trained as a physicist in England and Germany in the sixties and seventies of the last century, and lived into the thirties of this. Several of his books offer excellent reading, and the same idea on which I now am dwelling occurs in three at least; I take it from the historical retrospect which he delivered as a series of lectures in 1908 in Calcutta.[3] He is speaking of the eighteen-seventies.

> I think I interpret correctly the recollection of those who passed through their scientific education at that time, when I say that the general impression they received was that, apart from their work, a reputation could only be secured by improved methods of measurement which would extend the numerical accuracy of the determination of physical constants. In many cases the student was led to believe that the main facts of Nature were all known, that the chances of any great discovery being made by experiment were vanishingly small, and that therefore the experimentalist's work consisted in deciding between rival theories, or in finding some small residual effect which might add a more or less important detail to the theory.

Schuster is a mine of good quotations, but I dare take the time for only one more, and this because someone told me years ago that Kirchhoff was the originator of the sixth-decimal-place remark. I have not found it in any of his few speeches or general articles, but this is what Schuster avers on the basis of long friendship:

> Kirchhoff did not anticipate new facts being discovered leading to a revision of fundamental conceptions. When I told him of the discovery then made in England, that light falling on the surface of a bar of selenium altered its electrical conductivity, he re-

[2] *Théorie analytique des probabilités*, p. ii. I am indebted for this reference to Pierre Lecomte du Nouy and Alexander Weinstein.

[3] *The progress of physics during 33 years (1875–1908)*, (Cambridge, University Press, 1911).

marked 'I am surprised that so curious a phenomenon should have remained undiscovered until now.'

Relying on these quotations and on some others which there is not time to repeat, I now infer that the phase of depression and discouragement in physics extended roughly over the last four decades of the nineteenth century. It began about as soon as the laws of thermodynamics were solidly established, and it ended when even the most classical and the most isolated of physicists could no longer remain impervious to the knowledge of such discoveries as the Zeeman effect, the x-ray, the radioactive substances and the quantal explanation of the blackbody spectrum. In this depression of 40 years, was really *nothing* of fundamental importance being found? Well, I should hardly say so, inasmuch as those 40 years contained the development of the kinetic theory of gases and the electromagnetic theory of light and the discovery of the Hertzian waves! (After listing these examples I realized that Maxwell, whose optimism was not dampened by the depression, was largely responsible for all.) Here I am already going to break my promise not to quote you any more from Schuster. He comments on the fact that the electromagnetic theory was developed in Cambridge while the electric waves were found in Germany, and says that it was because in Cambridge everyone believed at once in Maxwell and nobody wanted to waste his time confirming the theory, while in Germany there were conflicting schools of thought and people set out to find which was right.

I should like to be able to tell you why this great wave of despondency swept over so much of the physicists' world at that particular time, and all the more so because I should like to be able to predict whether another such wave is mounting; but here I am reduced to speculation.

This idea that all the fundamental laws were known—how can it have arisen in 1860 or thereabouts? Let us grant that gravitation was fully comprehended, forgetting that Einstein was destined to find something further to say of it. Let us even grant that the electrodynamic forces were fully understood, though for 1860 this seems premature. No one was ignorant of the fact that the forces of cohesion and capillarity and chemical affinity are very different from those. Did the physicists of the eighteen-sixties feel a complete satisfaction with the macroscopic theories of elasticity and surface tension, and a complete indifference to the intermolecular forces which lie at the bottom of all? Or were they convinced that the intermolecular forces are forever beyond our reach, so that there was no point in leaving the frontier of physics open to include them? Or did they think that intermolecular forces are the affair of the chemist? There is, of course, no surer way of killing the future of a science than to limit its scope so stringently that almost anything that can conceivably be discovered will fall perforce into the lap of some other science. I suspect that those forerunners of ours had abjured a good deal of fertile territory which they ought to have kept, and that was one of the reasons why they thought that their soil was exhausted.

Again, what was it that they wanted to measure with such accuracy? Maxwell says: "The great physical constants." It is sometimes dangerous to accept the description of a feeling from a man who does not share it, as Maxwell certainly did not share the feeling about the sixth place of decimals. However, let us accept it and look over the dreary situation thus presented. Birge in his celebrated tabulation (and how I wish that those gentlemen of the depression could come back to look upon it!) lists about 50 constants, not including the masses of a large number of atoms. But Birge's first table was of 1929, and we are thinking about a time beginning as early as the eighteen-sixties, when fewer than half of the 50 could even have been imagined. No one of Maxwell's time knew enough to conceive of h or e/m, the radiation-constants or the fine-structure constant, the Compton shift or the Zeeman separation; no one hoped for more than the roughest guesses of the size of the Avogadro number; no one knew of any special reason for measuring the density of calcite to the sixth significant figure. The prospect held out was that of putting extra significant figures onto such numbers as the calory, the ohm, the liter, the constant of gravitation and the velocity of light. I think there are many of us here to whom such a prospect would not appeal; but it has appealed to many of the greatest of scientists, and it did appeal to Michelson as his reputation proves, and that I think is why the last and the greatest of the upholders of the idea was Michelson.

Maxwell notwithstanding, could there have been other things which our predecessors intended to measure with ever-strengthening accuracy? The atomic weights, of course, they left to the chemists; that was one of their unnecessary and deplorable sacrifices, not to be undone until with the discovery of isotopes the physicists reannexed the field. I cannot believe that they intended to chase the sixth decimal place in such measurables as the compressibility of rubber, the permeability of iron, the shear modulus of bronze or the density of pentane. Had they done so, they would soon have found that they could not get reproducible results with different samples.

Could they have been thinking of spectrum lines? This I regard as my best guess. Spectroscopy came into being in 1859, and from then onward there was steady amelioration of prisms and of gratings. The closing decades of the nineteenth century were the years of amazing improvement in gratings, as the decade of the nineteen-thirties was the time of amazing improvement in cyclotrons, as the decade which we now are traversing seems likely to be regarded as the time of amazing improvement in electron microscopes. The resolving power of gratings grew steadily higher, but all the while the lines on which they were set remained in many cases of the sharpness of knife blades, as if provided by Nature to gratify the passion for delicate measurement. It is strange to reflect that the notion of the "terms," in which now we find the best fundamental reason for seeking after accurate wave-lengths, was completely unknown in those years of the triumph of spectroscopy; but I suppose that there were other incentives, such as that of wanting to distinguish between nearly-coincident lines of different elements, the more safely to recognize these in spectra of unknown sources or the spectrum of the sun.

Now let us try to place ourselves in the physical world of our grandfathers' imaginings, the stage-setting for the phase of depression. There was a host of material particles, probably imagined as the hard massy spheres of Newton but with the power of vibration added, attracting one another with various forces. Newton, and the great mathematicians who followed him, had found out how to deal with the responses of masses to conservative forces, so nothing remained except to find the laws of the forces. Newton himself had discovered that of gravitation, Coulomb and others those of the electric and the magnetic forces, while those of the intermolecular forces were deemed to be either unfindable or not worth trying to find or the business of chemists to find. These particular forces made themselves manifest in such phenomena as those of elasticity and surface tension, of which the macroscopic laws were known in a satisfactory way. The laws of thermodynamics attended to the relations between heat and mechanical energy. Around the fringes of matter there hovered a strange and unquiet ghost, known by the name of electricity. The atoms of matter were wiggling, and between them there was a wiggling elastic solid known as the aether which transmitted their vibrations in the form of waves of light; and the spirit of Lord Kelvin moved over the face of the aether and tried to interpret the atoms as corkscrews or curlicues in the substance thereof. In this simulacrum of the world our forefathers walked about like a landowner on his estate, and they measured the wave-lengths of the wiggling aether in order to learn the frequencies of the wiggling atoms, and they measured gravitation and elasticity and surface tension and refractive index and whatever else they could find, according to the precept "whatsoever thy hand findeth to measure, measure it with thy might"; and they tried to get their clutches on the evanescent ghost, but with indifferent success.

Probably you think that in speaking of electricity as a ghost, and an evanescent one at that, I am letting myself be carried away by a passion for rhetoric. Hearken to this, which comes from an article published in 1895 (in the *Engineering Magazine*) by the first president of the American Physical Society. He was not at the time the first president of the Physical Society, for the Society was not to be founded for another four years; but he was destined to become it, and his name was Rowland. I quote:

> It is not uncommon for electricians to be asked whether modern science has yet determined the nature of electricity, and we often find difficulty in answering this question. When it comes from a student of science anxious and able to bear the truth, we can now answer with certainty that electricity no longer exists. For the name 'electricity,' as used up to the present time,

> signifies at once that a substance is meant; and there is nothing more certain today than that electricity is not a substance.

This fantastic statement requires to be explained to the younger generation. As fully as the explanation can be given in one sentence (which is not very fully) Rowland believed in the substantiality of the aether, and of the lines of force in the aether and perhaps of the energy in the aether; but he regarded the electric charges as being nothing but the termini of the lines of forces, and he did not want to confer upon those termini the dignity of substance. Anyone here could now say the appropriate thing, but I will let Henri Poincaré say it for all of us. This is Poincaré opening the International Congress of Physics at Paris in 1900:

> Fifteen years ago, was there anything more ridiculous and more naively old-fashioned [*plus naivement vieux jeu*] than the fluids of Coulomb? And yet here they are coming back under the name of electrons.

Actually they had never been completely away, at least not completely away from the mind of Maxwell. It is Maxwell's classical treatise of 1873 which is the fine flower of this anti-electricity viewpoint, and yet listen to the passage in the treatise which attempts to cope with electrolysis. What we call Faraday's laws simply will not fit into the theory, and so:

> Suppose that we leap over this difficulty by simply asserting the fact of the constant value of the molecular charge, and that we call this constant molecular charge, for convenience in description, *one molecule of electricity*. This phrase, gross as it is, and out of harmony with the rest of the treatise, will enable us at least to state clearly what is known about electrolysis, and to appreciate the outstanding difficulties.

So after all electricity was not quite a ghost in Maxwell's mind in 1873, though it *was* a ghost in Rowland's mind in 1895. Not long thereafter the wheel had come full circle, electricity clothed itself once more with substance, and the aether became a ghost.

Will the aether remain a ghost? It is foolhardy to be a prophet, but I suppose that by the title of this speech I have committed myself to making at least one prophecy. Therefore, I foretell that the aether will come back. This old and faithful comrade of the human mind in its imaginative flights cannot be dead forever. It arose to satisfy a deep-implanted appetite of the intellect; the appetite seems dormant now, but it will reawaken demanding to be fed. I do not predict the return of the aether for tomorrow, nor perhaps for my time, but I think that some of you will live to welcome it back. The place of its return is equally beyond my foresight. In the eighteenth century the aether resided on the continent of Europe, and was spurned in England; in the early nineteenth century it was banished from the continent and found a happy home in the British Isles. Perhaps it will come back in 1980 in Australia.

Now to examine the question whether a new phase of depression in physics is to be expected. To summarize and extend my conjectures about the previous one: I suggest that it was due to the concurrence of four defective ideas:

(1) the idea that the fundamental laws of mechanics were all known;

(2) the idea that the laws of the intermolecular forces were unknowable;

(3) the idea that chemistry belonged to chemists—to which I will add, as a mere guess, the idea that engineering belonged to engineers;

(4) the idea that Nature, or at any rate the part of it to which physics was entitled, had already been combed so completely for new phenomena that if anything new should turn up, the remarkable thing would be (as Kirchhoff put it) that it had eluded discovery for so long.

Now, it is evident that not one of these four ideas is entertained today.

As for the first: we have quantum theory and we have relativity, and I am informed by those who should know that the union of the two is not completed, and that nuclear theory continues to be rebellious. We have also statistical mechanics. Poincaré in that 1900 speech said of it: "It has cost much trouble and has not been good for much, but may become so" (*elle a côûté de grands efforts et a été en somme assez peu féconde; elle pourra le devenir*). Well, it has cost a good deal more trouble since then, and has been stood on its head or, as most prefer to say, it has been revolutionized; but Poincaré was right, it has become good for a great deal. I think that we may rely for quite a while on the competence of these three to protect us from the belief that the fundamental laws are already known in full.

As for the second: it is only for the sake of the record, and not because you do not know it, that I mention that the intermolecular forces are no longer deemed inaccessible. Not only have we gone down to them, we have gone down beneath them by investigating the forces between nuclei and electrons, nuclei and other nuclei, electrons and electrons, nuclei and neutrons. Here is perhaps the most definite sign of impending exhaustion: Most people seem to be convinced that the forces between atoms are electrostatic forces acting in part overtly, but in part masquerading under the guise of "exchange forces," and that if we cannot predict the properties of the sulfanilamide molecule in advance, that is merely because the mathematics is too difficult. This is just the sort of feeling that might lead to a new depression phase; but the nuclear forces are still mysterious, and I expect them to save us for a while.

As to the third idea—the one which I paraphrased as the notion that chemistry belongs to the chemists, engineering to the engineers, et cetera—I do not really know how strong it ever was, but I am sure that it is dead now, and deader by far than the aether. Our grandfathers may have tilled the home fields in contentment, but we are imperialistic. We have already taken back a good deal of the field which they abandoned to chemistry, and are casting covetous eyes on most of the rest and on quite a piece of biology. By "we" I have been meaning the community of physicists; but now construing "we" to mean for the moment just the American Physical Society, I can say of and for it that we intend to hold our patrimony, and we have evinced this intent by founding in the Society a Division of Electron and Ion Optics and a Division of High Polymer Physics, with others yet to come.

As to the fourth idea—but let me leave that for a little; I must attend to the sixth decimal place which figured in the last depression era.

Should I say that accurate measurement is a passion of the phases of depression, while times of prosperity are times of laxity? There is some truth in such a statement. A time when theories are burgeoning is likely also to be a time when their demands on numerical checks are not yet very stringent. Our grandfathers were still beneath the sway of the great traditions of celestial mechanics. The virtuosi of that science, with their fundamental laws all known and their approximations highly convergent, were able to make close predictions, of which in turn the astronomers with their highly-developed instruments were able to make close tests. Our theorists of quantal chemistry and nuclear physics are not likely to set up a loud clamor for the sixth significant figure in the measurements, so long as they have so hard a time in agreeing with the second.

Nevertheless this present time of prosperity happens also to be a time when the physical constants are being measured more sharply than ever before, and with the novel possibility of cross-checks. What Maxwell called "the great physical constants" were not connected with one another; one man could measure the mechanical equivalent of heat and another the speed of light and another the constant of gravitation, and each could look with entire placidity on the results of the others, knowing that his own would not be thereby called in question. According to the fundamental theory of our time, many of the "great constants" are combinations of a few still greater constants which are called "universal." If this is true there are interrelations among the great constants, such that if someone changes the accepted value of one by ever so little, all the rest are likely to go out of kilter, or in the favorable case, into kilter. Nothing could better have pleased that untraceable physicist who looked for the future triumphs of his science in the sixth decimal place. Many of us here remember what was long called the "discrepancy in the values of e," which was traced to a fault in the fourth (I think it was) significant figure in the value taken for the viscosity of air. Many will remember the "discrepancy in the values of e/m," which was tracked down to what some of our colleagues now would call faults in electron optics. Many will remember the discrepancies among the reported atomic masses of the isotopes of the lighter elements, which were tracked down to a fault in the determination of the hydrogen-to-helium mass ratio. Measurements to a high significant figure banished these discrepancies—but also, measurements to a high significant figure had evoked them, only these other measurements came earlier and are supposed to have been worse. I

think that the incentive to such measurements will remain with us for yet awhile, so that the present era and the early future will be remembered as a time in which high significant figures were held in high honor.

But now I am exceeding the rightful time of this address, and I must close it by disposing of what some little time ago I called "the fourth idea." The viewpoint of this lecture is that there are four prerequisites for the birth of the fallacy of the mature economy in physics. Three at least do not exist at present. We do not suppose that we have quite mastered the fundamental laws; we do not regard the forces between the elementary particles as being beyond our reach nor yet as being exhaustively known; and we do not restrict the field of physics so narrowly that our science is in danger of dying of its confinement. Do we suppose that the phenomena of Nature have been so thoroughly combed that nothing strange, nothing novel, nothing curious and nothing unforeseeable remains to be discovered?

I can scarcely remember having heard this idea expressed in my time as a physicist. It may exist here or there, but assuredly it is not widespread. If it ever is reborn and starts to ravage the minds of those who might otherwise investigate, I count on industrial physics to quell it. Industrial physics could not acquiesce in such a doctrine, without signing its own death warrant: It will neither wish nor need to do so. If anyone is paralyzed by the recurrence of the feeling that there is only one system of the world and somebody else has discovered it, the demands and desires of industrial physics will be able to restore him if he wants to be restored. In our time at least, opportunity will not vanish, incentive will not fail, the well is not going to run dry and we shall not reach the bottom of the cornucopia of Nature. Now I will ask Maxwell to finish my lecture for me. "We have no right to think otherwise of the unsearchable riches of creation, or of the untried fertility of those fresh minds into which these riches will continue to be poured."

The Outlook for the Physicist and Prospective Physicist in Industry*

Albert W. Hull
General Electric Company, Schenectady, New York

THE coming year will be a transition period for physicists. Many will be released from war work and will be faced with the problem of deciding what they are to do. Industrial physics is one of the opportunities that will be open to them. They will want to know what it is like, what salary it offers, and what the demand for industrial physicists will be. A discussion of these questions therefore is appropriate.

NATURE OF THE JOB

As to the nature of the job, it's a hard life. Abandon all hope of ease, ye who enter industrial physics! Your days will be filled with insoluble problems, your evenings with the never-ending struggle, by scientific reading, to keep abreast of knowledge in an ever-widening range of subjects. Your job, like a woman's, will never be done. Like a man without a country, you will never be able to settle down into a groove and say that this is my home, my job. You will be an absent-minded husband, a preoccupied father, a poor playboy.

But it's an interesting life. There is a rainbow at the end of each day's journey, a thrill in each morning's anticipation of the tasks ahead. Life is a continual game, a contest with nature, which always plays fair. The harder the problem, the greater the satisfaction in its solution. Only insoluble problems desired, please!

The physicist's life is interesting, not in spite of the fact that it is hard, but because of it. Who invented the idea that an easy job is a good job? Does anyone really enjoy an easy life? No worries, hence no thrills; security, hence staticism. Those who wish such a life should not enter the field of physics. When I was very

* Address of the Retiring President of the American Physical Society, January 15, 1944.

young, I worked for a short time in a factory making wooden caster-rolls. My job was to use the scrap ends that were left from the big lathes. I envied the men on those lathes; asked if I might have a piece rate like them, and was advised that I would fare better with a day rate, but insisted. In three weeks, I was making twice as much as the men on the big lathes. But that is not the important point. It is that I enjoyed my job. Noon came too soon. I enjoyed it because there was an incentive to do a better job each day.

I believe that this challenge to do a better job each day is the thing which makes the physicist's life interesting. It is inherent in the nature of his job. The ocean of scientific ignorance is so vast that Truth is forever beyond reach. The goal of each day's work is to get one step nearer to Truth.

I used to play chess with a colleague who was much my superior and invariably won. But he never allowed the game to stop short of mate. "You may not win," he said, "but you still can make a good move. There is no position on the board, short of mate, in which an excellent move cannot be made." To him chess was a series of good moves. The physicist's job is a series of good moves. In the contest with Nature, he never wins, but always can make a good move. And the pleasure of the game is in the moves, rather than in winning.

What I have been saying about physics, is, of course, true of other sciences, and might apply to any kind of job. Mr. Charles E. Wilson, former president of the General Electric Company, who is now Vice Chairman of the War Production Board, has been urging war industries to adopt "incentive pay"—more pay for more production—as a means of increasing war output. Such an incentive could transform any job from being easy, and hence dull, to a contest with perfection, which is the type of job we have been discussing. The implementing of such incentive plans is in itself a task of this kind, difficult and impossible of perfect accomplishment, but susceptible to progress; an opportunity for good moves by labor and management.

It is not to be expected that the same incentive will appeal to everyone. For example, a young man who was working in our laboratory some years ago asked to be transferred to the vacuum-tube engineering department, with the comment "I want to make tubes that work." The research method of testing each day's product to destruction, in order to learn as much as possible, left him unsatisfied. His was a temperament that craved fixed rules and attainable objectives. Another man left our laboratory for the commercial department. He wanted more social contacts than were afforded by research work. Such changes are to be commended. The most important part of education is finding out what one most enjoys doing, and the final test of this is actual trial, which should be made as early as possible. One method of determining this is summer work, such as a summer in an industrial laboratory. For several years before the war our laboratory invited a limited number of young men to come and work for the summer, not for what they might accomplish, but as a means of mutual acquaintance, and as a test of their fitness and aptitude for research.

A good criterion of qualification for a physicist's career is one's reaction to the report that something can't be done, or has been tried without success. A personal example, if it may be pardoned, will illustrate this. In 1914, Sir William Bragg came to our laboratory and described, in his delightful manner, his pioneer work on x-ray crystal analysis. At the end of the lecture I inquired whether he had determined the structure of iron, which was of interest for the light it might throw on magnetism. He said, "No, we have tried it, but haven't succeeded." The next day I began working on x-ray crystal analysis. To a physicist the statement, "I have tried and failed," is a stronger challenge than any amount of advice.

To summarize: The physicist's job is one requiring hard work, in which the most important happiness-factor is the challenge of his task. For the real physicist, the one who has found the right job, this anticipation and joy of accomplishment outrank the other important incentives of salary, pleasant working conditions and public applause. So, if you are a young man considering physics as a profession, the criterion should be, not the probable demand for physicists, nor the salary, but the challenge of the job. If you cannot get a thrill out of the anticipation

of solving some of the difficult problems which physics presents, you should think twice before entering its portals.

REMUNERATION

I have placed salary second, but it is by no means to be ignored. Want is one of our most useful incentives. It is a mainspring of daily life, whose constant pressure keeps us going through days of monotony and failure. Frail human courage needs this spur. Complete freedom from want would be a doubtful blessing.

What pay can the industrial physicist expect? On a relative basis this question is easy to answer: The pay will be essentially the same as he would receive in any other job that utilizes the same qualifications, namely, in a university job, whether teaching or research, or in other branches of science and engineering. Several agencies are at work to insure this result:

First, between the industries and universities there is a continual interchange of research men in both directions and at all levels. Supply and demand operate to keep the salary scales comparable in these two competitive markets for physicists. This natural process takes due account of factors affecting the desirability of the job, such as vacations, pleasant working conditions and stability of employment. A small company with uncertain future should and does bid higher for good talent than an established firm or a college with a guaranteed tenure. The dignity and esteem of the college position is also a factor, which makes some small-college jobs more attractive than industrial jobs at comparable salary. In the past, there have been more physicists in university work than in industry, so that the opportunity for interchange has sometimes been limited. This will be remedied if the expected increase in industrial research materializes.

Second, within a single laboratory, all the men, irrespective of subject, are arranged in a single rating list in order of merit. This is the practice in our laboratory, and I believe a similar procedure is followed in others. The rating takes into account as many factors as possible, for example, knowledge, initiative, cooperation, leadership. It does not determine the salary level, but aims to assure that the men are in the right order as regards salary, that is, that no physicist of greater merit is below another physicist, chemist or metallurgist of less merit. The list is reviewed and revised twice each year.

Third, within a given industry, careful comparisons are made between the salary scales for research and engineering, with the object of assuring that they shall be the same for equal ability. It is, of course, difficult to compare dissimilar jobs, but the errors will be those of judgment, and not any preferential rating of one profession over another.

The discussion thus far refers only to relative salaries among members of the same professional class. This is what counts most; in fact, it is the only thing that counts so far as happiness is concerned. The salary must be adequate for your scale of living, which is determined principally by that of your friends; and these will, in general, be your peers, people of similar professional tastes. You must be able to do the things that they do, and not be embarassed by having to live differently.

The relation of the physicist's salary to that of other groups, on the other hand, is not important, unless one has abilities in more than one field, so that it is necessary to make a choice. In such a decision the choice should be weighted heavily on the side of congeniality of the work, as I have already emphasized. The relative salaries of different groups may vary widely from time to time, according to demand. In the postwar world, the salaries of miners may be higher than those of physicists. If this result comes about naturally, that is, if the higher salary is necessary in order to induce men to enter the mining profession, then it will be accepted by everyone as fitting and proper. If it should result from political pressure, physicists will disregard it, considering it an example of probability-fluctuation in an ever-present phenomenon.

Finally, the actual level of salary is not of critical importance, provided it is safely above subsistence, as is true for all groups in this country by a large margin. Certainly there is no close correlation between salary level and happiness.

The point of this discussion is advice to a young physicist, or one who is considering physics, not to be influenced too much by what

he hears about salaries in different professions. It is probable that in the lines for which he is qualified they are not very different, and they are not of primary importance. Love of the work, and natural fitness for it, are the real criterions. It is better to be a good machinist than a poor physicist. Many a young man has been ruined by going to college; that is, his college degree made him unwilling to do the kind of job which he could do well. Other men have been tempted to enter uncongenial careers because of salary considerations. For example, a young man, fresh from an engineering school, came to our laboratory about 1926. It was the period when money was made easily and young men's heads were turned by the demand for their services. He was frankly critical of our salary scale, and announced that he had no intention of working for such wages. He had observed that young men in the commercial branch appeared to rise faster, and he proposed to enter that field. Fortunately, the General Electric Company was offering courses in business administration to its young employees, the first course being one in accounting. This he decided to take. His distaste for it grew, and at the end of the year he hated it so much that he said no conceivable salary could tempt him to enter a business career. From that day he has been happy in his research work, and very successful. This example should not be construed as indicating that physics is a better profession than accounting; that is not true; but that the choice should be made on the basis of love of the work rather than salary. A man can be happy on any salary, within wide limits, provided his friends are in the same boat. But he cannot be happy in an uncongenial profession.

DEMAND

More important than salary is the question of getting a job. What will be the demand for physicists in industry? Can they get jobs? This is a pertinent question, since many good physicists today can remember the time when the demand for their services was very low. That was an abnormal time, a period of financial crisis and social reform. In discussing future demand, such periods must be treated as exceptional. They should not be disregarded, however. They will come again. Any progressive society must make mistakes, and industrial dislocations are sure to follow. The seriousness of this problem is sufficient to justify putting it at the head of our discussion about demand.

A scientific approach to the problem of dealing with such abnormal periods would be to expect them, to discount them in advance on the basis of their probability and to provide against their impact. This is the method used in experimental physics. In vacuum-tube research, for instance, the experienced physicist knows from statistics that some unexpected accident will happen, on the average, to two tubes out of three. He makes the proper allowances in cost and time schedules, and is able then, not only to be unperturbed by the accidents, but to view them as assets, from which valuable lessons may be learned. The bad tubes are not tragedies; they are part of the job, expected and discounted in advance. In the same way, society should insure itself in advance, during its seven years of plenty, for the seven lean years, or whatever number an actuarial calculation predicts. An effort in this direction was under discussion at the time the war broke out, in the form of a special fund, ear-marked for research, to be built up during normal years and used to keep research going during depressions. It is easy to see difficulties in carrying out such a program, but it is well to remember the rule of research, that a solution does not have to be perfect in order to constitute a step in advance. The coverage should preferably be broadened to include engineering and perhaps other fields; for it is socially impractical to keep one group busy while another group of comparable training is idle. Some provision should be made, however, for the difference in risk between research and engineering. It has happened in the past, and will undoubtedly be true in the future, that research becomes a luxury item for many industries when depressions come. An industry must retain a fair complement of engineers in order to carry on at all; but research, a long-term gamble, can be dispensed with temporarily.

We turn now from the consideration of depressions to that of normal periods, and attempt to answer the question, What will be the *normal* demand for industrial physicists? There are several reasons for believing that the demand will exceed the supply for many years to come. In the

first place, physics occupies a position in this war similar to that of chemistry in the first world war, and hence may expect a postwar popularity comparable to that which chemistry has enjoyed in the past two decades. In fact, there is reason for expecting that the increased demand in the case of physics will be even greater than in that of chemistry, in proportion as physicists were less known. It is a rare occurrence that a census taker has ever heard of a physicist, and the task of explaining is such that one is often tempted to register as a chemist.

In the second place, the demand will be helped by the greater employability of the physicist himself, that is, his better attitude toward industrial work, gained as a result of our cooperative war effort. The reputation of physicists in industry has suffered, in the past, from a frequent attitude of superior knowledge—perhaps the expression of an actual inferiority complex, due to lack of familiarity with industrial life. Young physicists are reported frequently to have begun —and sometimes ended—their industrial careers by telling the factory manager just how to run his plant. It is desirable that such mistakes should be prevented in the future, for the best stimulus to demand is satisfactory performance. What is needed, of course, is a proper respect for the other fellow, a recognition that the engineer, the mechanic, the executive, the accountant, the salesman, each has a job just as important as that of the physicist, and generally knows how to do it much better than a physicist could tell him. The first step toward such understanding is acquaintance, which might be accomplished by more frequent interchanges between university and industrial physicists; for example, a freer flow of teachers into industry and vice versa, nonresident college lectures by industrial men and leaves of absence for teachers to be spent in industrial laboratories. Such a program would help industry evaluate the physicist. Physicists are more useful than has been realized, and better and more versatile than they themselves knew. The nuclear physicist has found that he can "convert" to electronics in a few months. Teachers are discovering that they have executive ability, and many will be available after the war as directors of laboratories.

A third factor in the demand situation is a growing public recognition of the *need for research* as evidenced, for example, by the "Bill to Mobilize the Scientific and Technical Resources of the Nation" now before Congress. This bill may be viewed either with alarm, because of its faults, or with welcome, as a call to action. I prefer the positive view. The bill undoubtedly is faulty; that can be changed. But the public interest is something that will remain, and should be heeded. It is the voice of society, saying, "We want more research." Physicists should welcome this call. They want to do more research. How to finance and manage it is a difficult problem, as always, but a way *can* be found. The interest shown by the public is an implicit demand that science, industry and government get together and find a way. I am confident that our physicists will respond to this call.

One word of caution is needed: We should not expect this expansion of research to happen overnight; growth is a gradual process. An expenditure of a billion dollars a year for research is not too much to look forward to, but if a tenth of this amount were available next year, it is very doubtful that it could be spent wisely. There aren't enough good scientists to use it. In the words of a prominent industrial executive, "The limit of our growth will not be money, but the number of qualified men who can be found."

It is also well to remember that something could be lost by hasty action. The fine spirit of cooperation among scientific men is unequalled in any other class of workers or in any other period of history. This spirit might be injured if science were made a political football or if the direction of research were saddled with a political hierarchy.

VALUE OF RESEARCH TO INDUSTRY

If science is to escape political control, industry must respond to the demand for research with a greatly increased program. Can industry afford to do this? Will industrial research pay? The answer to this question depends to a considerable extent on what happens to our patent laws. The opinion is general that research has paid in the past, though no figures are available to prove it. There is even greater agreement on the answer

to the negative form of this question: Can industry afford not to do research? The answer is "No." Research is coming to be looked upon as an industrial vitamin, without which an industry becomes decadent and its products obsolescent. Therefore, I think there will continue to be industrial research and an increasing amount of it, whatever the laws.

This will certainly be true of the type of research done in works laboratories, namely, product-improvement. Such work is part of the industrial physicist's job, in many cases the largest part. Let no physicist who has found a useful and interesting place in this type of work feel that it is beneath his dignity, or that he should be doing something more important. Any operation, however commonplace, becomes an important job for the physicist when it needs his services. For instance, the most important current problem in vacuum-tube construction is not the sealing of metal to glass, but the vacuum-tight soldering of metal to metal. Thus, soldering, a plumber's art of yesterday, is today a number one priority job of physicists.

Perhaps "important" is not the right word to describe the feeling, on the part of some young physicists, to which I refer, and which I respect. It is a feeling that they ought to be doing something which makes use of what they have learned in the graduate school. To anyone who is worried about this, I would say that this feeling will soon change. He will find that the knowledge represented by graduate study is a small part of what is needed to make a good physicist. I rate graduate study in physics very high, but not for its factual content. It is rather the attitude, caught more than taught, that is important. It embraces scientific honesty, self-discipline, the habit of scientific reading, belief in fundamental principles, self-confidence in one's ability to get to the bottom of any problem, an absorbing love of the job that makes work play, the mysterious metamorphosis that turns the student into a physicist. I suspect that a similar miracle happens to any young man who is trained under a master, in whatever field. To one who has experienced this miracle, no task is either too hard or too trivial.

Next to product-improvement, the principle type of industrial research is the development of new products. Here the case for profitableness is not so clear. Pioneer development is very expensive. For example, the General Electric Company spent several million dollars on the development of the mercury turbine before a single successful turbine was built. It is also a gamble. The success of the mercury turbine venture was in doubt up to the very end. Hence it is not surprising that many companies are cautious about undertaking this type of research. One frequently hears that "it is better to let someone else lose his shirt in pioneer effort, and enter the field later, when the success of the product is assured." The only deterrent to this procedure, other than a possible shortage of pioneers, is patents, and it has been suggested recently that the patent law should be modified, so as to give these latecomers a chance. It is for just this reason that a patent law is needed, namely, to protect the pioneer who is willing to risk "losing his shirt," so that we may continue to have such pioneering.

Not that there would be no pioneer development at all, if the patent law were repealed. There is another kind of protection, namely, secrecy, which could be used to safeguard investment. It is so used today by certain industries, such as the photographic film industry and some chemical industries, whose products are hard to protect by patents. But not all products are amenable to secrecy; it would be hard to keep a mercury turbine secret. Even if it were possible, no one, I think, would consider the substitution of secrecy for patent protection to be a change for the better. Certainly, scientists would view such a change as a calamity, since it would substitute locked doors for the excellent cooperation that is so great an asset of science today.

The third alternative, namely, government-financed development of new products, though necessary in war, is so un-American as to be unthinkable in peacetime. For it is just in this field of new developments that private initiative is most efficient; while government, though an effective agent for furnishing common services that have become standardized, is very unsuited to operations which require initiative and judgment.

Therefore, it is desirable that incentives of some kind be found, whether of the type offered

by our present patent law or of some other form, which will result in an increased rate of development of new products by industry. Physicists should have an important part in this developmental work.

The two kinds of research that we have been considering, improvement of products and development of new products, are the obvious responsibility of industry. Pure research, on the other hand, that is, research whose aim is to obtain knowledge rather than make something, has generally been done in endowed or state-supported institutions. Such research is a proper public expenditure, since its benefits go to everybody, even transcending national boundaries. It is the one field in which international cooperation is already a reality.

Whether industry can afford to have a share in this pure research is an unanswered question. I am one of those who believe that it can. For one thing, it should do a certain amount as a contribution to knowledge, in partial payment to society for the values it receives from the research of others. In addition, there are benefits to be expected, of two kinds. The first and most obvious is inventions. New discoveries lead to new and unexpected applications, which may be epoch-making. The gamble is big, but the stakes are high. The second benefit is the stimulus which pure research can give to development and engineering. In the cooperation of many departments, each gives and receives, and the gain is mutual and large.

The gain from cooperation is greater than is realized, even by those who prize it most. I talked recently to a young metallurgist who had worked for a year in our laboratory, while taking the "advanced course" at General Electric, and then had gone to a smaller laboratory. "My work is very interesting," he said, "but you have no idea how helpless one feels out there. A few other technical men are there, but no one to whom I can talk about my problems." This remark is typical; I have heard it often from other men in small laboratories. It can happen even in a large laboratory. It emphasizes the need and value of cooperative group effort.

A couple of everyday examples will illustrate this. In one of our war jobs we needed some means of air-conditioning a metal mercury-vapor tube. The tube operated at 200°C, and there was needed an insulated wire winding and a non-metallic housing cylinder that would stand this temperature. Glass-insulated wire was obtained from one of the factory departments, and was impregnated with a new high temperature Silicone varnish by our chemists, who also furnished us with sheet Silicone for the housing. In two weeks the problem was solved. On another job some sheet Invar was needed. One of our metallurgists was able to provide curves that showed the correct composition for our purpose. Another metallurgist agreed to melt a 40-lb ingot in his induction furnace the next morning, and deliver it that same day to the factory forge shop for forging. Following this, it was rolled to the desired thickness in our laboratory metal-working department, spun into form in the machine shop and incorporated in a tube, all within two weeks. There was no haste about these jobs. They were not "rush" projects, but just everyday problems. Two points are to be emphasized in this matter of cooperation. The first is the advantage of having grouped together in a laboratory such a wide range of specialists that expert help can be obtained on any problem which arises. The second, and more important, is the willingness of these departments and individuals to cooperate. This is a precious thing, easily lost, but slow of growth. Like Portia's quality of mercy, it "is not strained." It could not be obtained, for example, in a government laboratory by passing a law.

This brings us to the main point of our discussion, namely, What kind of industrial laboratories are wanted? Is it undesirable in a democracy to have good industrial laboratories? We have been told by no less a person than the Vice President of the United States that, if there are to be any large laboratories, they should be government laboratories, otherwise they monopolize research and make it hard for the little fellow to compete. I am going to suggest an alternative solution: that the little fellows increase their efficiency, by getting together and cooperating, so that they will be able to compete. Any large company, ours, for example, is usually a group of small companies or departments, whose dealings with one another are on a strict accounting basis, and each must balance its

own ledger. The lines of work of the different departments in the General Electric Company cover a wide range, from vacuum tubes to superchargers. Yet these diverse departments support a common laboratory. I will not say that they have solved the problem of how to divide the expense, but they have been able to carry on for 40 years. Similarly, any group of small companies, not necessarily making the same product, could combine on research. The only requirements are the will to carry on research, cooperatively, and patience to wait for growth. An appropriation of money does not make a laboratory, nor does a building or even a group of men. A laboratory is a living thing, with a heart and nerves and habits and ideals.

NEED FOR RESEARCH

We come now to the last and all-important question: Of what use is research to society? Is it just a fad? Much has been written about the amazing new devices and products that science will produce after the war. The effect of these predictions is dazzling and confusing. One gets the feeling that it will be necessary to run as fast as possible just to keep up with the show. Such a view of the future can do no good, and it is not even a true picture. Science can do all these things and much more, but they will not be done tomorrow. The future will begin just where the past left off, with frail humanity plodding along and making progress one step at a time. In the midst of these dazzling predictions we may keep our feet on the ground, even though our ideals reach the sky. As someone has said, "Hitch your wagon to a star, but watch the traffic signs." Therefore, instead of predicting the new products of science, I prefer to consider its problems. These are, of course, the old problems of humanity, which have always existed. What is new today is the will to solve them, and that is our opportunity.

The most immediate need of the world is food and shelter. If physical science can serve this need, it should be our foremost problem. We shan't be able to solve the problem completely; the world will be hungry and ill-housed for many years to come. But American scientists may contribute toward the solution.

For example, farm machinery has had very little research, especially small-farm machinery. The present plough was designed some 200 years ago, and today its action in exposing the soil to erosion is being criticized. The usefulness of the cultivator and hoe have been questioned recently. The possibility of covering up the soil, as a method of dealing simultaneously with weeds, insects, evaporation and erosion, is being discussed; it offers an interesting field for research, and a possible market for durable plastic sheeting. Plant vitamins and germination accelerators offer good research prospects.

Food processing is crying for research, especially methods of concentrating foods that will allow compact storage, without danger of spoiling or loss of vitamins and flavor. This is a problem for physicists and chemists, more than for agronomists.

Electrification of farms is a field for study in economical power distribution to small customers. Weather forecasting, as a science, is just beginning, and is important for agriculture as well as aviation. Long-range weather forecast is not beyond possibility. Both electrification and weather forecasting are problems for the physicist.

The housing problem is even more in need of research than farming. Wooden houses today are built precisely as in Colonial days, brick houses the same as in Pharaoh's time. New methods and materials should have been found by research, to offset the steady rise in wages and material prices. Since this was not done, the cost of building has more than doubled since 1900. In 1937 the American public spent six billion dollars on building. Half of this, three billion dollars, represents an increase that is chargeable to the unprogressiveness of the building industry.

Compare this record with that of an industry which has carried on continuous research during this period, the electrical industry. In 1940, Dr. W. D. Coolidge, director of the Research Laboratory of the General Electric Company, testifying before the Temporary National Economic Committee, said:

> The United States public paid about $90,000,000 for the lamps it bought in 1938. If it had to buy the carbon lamps of 1900 to produce the same amount of light, its lamp bill would have been increased by about $600,000,000 for that one year, $2,000,000 per working

day. That is a small part of the story. The lamps of 1938 through research were so much more efficient than those of 1900 that to produce with the latter lamps the amount of light used in 1938 would have raised the public's electric light bill for the same year by about $3,000,000,000, or $10,000,000 per working day. Thus research on lamps has given the public an annual saving of about $3,500,000,000, more than the cost of all the private automobiles sold in 1938 in the United States. But even this is only part of the story. The foregoing was calculated on the basis of average power rates for electric lighting in 1938. The average cost of power today is less than one-third of what it was in 1900, and in this reduction research has played its part. If the light used in 1938 had been produced by the lamps of 1900 with the electric power rates of 1900, the cost would have exceeded that of 1938 by over $10,000,000,000—$30,000,000 per day. Of course, the public would get along with less light for they could not have afforded such a lighting bill. What that would have meant in reduced safety and efficiency in industry, in reduced safety on streets and highways, and reduced comfort and convenience in the home cannot be evaluated in dollars.

Similarly difficult to evaluate in terms of money saved are the new electrical products, such as x-rays, refrigerators, radio, which benefitted mankind and gave employment to hundreds of thousands. But the addition of a single small unit may be used as a yardstick. The screen-grid tube is an example. Radio receivers once were made without it, and could be now, but they would require twice as many tubes and circuit elements, and would cost twice as much. The American people spent 400 million dollars for radio receivers in 1941. Without screen-grid tubes, the cost would have been double that value. Hence, the screen-grid tube saves the public 400 million dollars a year. These savings are the result of research work by the electrical industry, and are cited as a basis for gauging what other industries, such as building, may be expected to accomplish by research in the future.

Next to food and shelter, the greatest need of the American people is the opportunity to work. The problem sounds simple. We have plenty of factories of the right kinds, and we have people who want to work and are willing to spend all that they earn, buying the things which they, collectively, make. The cycle of earning and buying obviously closes at any level of employment, that is, whether the employment is 100 percent or only a small fraction. Of course the problem is complicated by the durable or equipment goods, which are bought by corporations rather than individuals. Evidently it isn't simple, as our experience during the last ten years has proved. It will not be solved by a stroke of genius or of luck, but only by a long series of small steps.

In the meantime, physical science can provide a tonic for this employment ill. The tonic is new products. New products are resistant to depression psychology, and experience has shown that they can be sold when old products cannot. In this way, physicists can contribute to the all-important job situation.

Finally, there is something more important than food and shelter and jobs. These alone cannot give happiness. In fact, they have very little relation to it. The More Abundant Life does not consist of things. In proportion as happiness is more important than physical comfort, so psychology and philosophy and religion are potentially more important than physical science. We may hope that they will some day shed more light on the great problem of human happiness. In the meantime, it is the privilege of physicists to contribute toward a happier world, first by finding pleasure in scientific accomplishment, and second, by helping others and by finding pleasure in the accomplishments of others; that is, by true cooperation.

The Offer of Physics

TO converse with great minds of all lands and all ages; to look on Nature with eyes that can see in space a billion years of the past and in a needle's point the universe of tomorrow; to apply the standard of precise measurement to all you do and all you ask of others; to carry keys to every natural science in the fundamental principles of your own; to talk on friendly terms with artist and engineer, mechanic and mathematician; to lose yourself in enthusiastic painstaking research and to join with others in attacking the unsolved riddles of the world of reality. This is the offer of physics, her demands a lifetime of service.

—Noel C. Little, *Bowdoin College.*

Man Power in Physics, Present and Future

H. T. Briscoe
*Indiana University, Bloomington, Indiana**

THERE is little need for me to review for you the critical manpower shortages in physics that have existed throughout the war period. The needs for physicists in the armed forces, in educational institutions, for research and development projects, and in war-related industries, and the inadequacy of the available and potential supply are as well known to all of you as they are to me.

It appears that the extremely critical character of the demands in this field was first generally recognized during the summer of 1942. At that time it was estimated that the nation's resources of physicists totaled about 7000, counting the 500 graduate students expected to receive degrees in 1942. It was estimated that the needs for physicists by January, 1943 would reach 10,900, and that by January, 1944 this number would be increased to 12,300. It was also estimated that the difference between visible supplies, as viewed in July of 1942, and the known needs would be about 3800 in January, 1944. In July, 1942, the War Policy Committee of the American Institute of Physics stated in its second report:

> The number of physicists in this country is small, only about 7000, and a substantial portion of these are already engaged in direct war work, leaving much too few to provide physics training for Army and Navy personnel and those needed for war research and production. Unless prompt, effective measures are taken, the shortage of physicists will be disastrously acute and no adequate program for training new physicists can be effected.

During the past 18 months we have seen all these predictions become realities and, today, the picture is even less bright than it was in the summer of 1942. There are still too few physicists to man the front lines of the battle fronts in the sort of war that only physicists can fight, and there are no reserves to throw in if sudden emergencies arise. Every physicist called upon today for some new service must be pulled from a job where he is already desperately needed.

What do we know of the needs for physicists and of the future supply as the situation stands today? I shall try to report to you briefly on the information that we now have on these two issues, and in so doing I wish to acknowledge my debt to the National Roster of Scientific and Specialized Personnel through which most of this information has been collected and made available.

During March, 1943, the United States Employment Service conducted a survey of current and anticipated employment of technical personnel by occupations. This survey covered some 15,000 establishments directly related in whole or in large part to the production of materials needed in the war program and estimated the demands of these firms for technical personnel during a six months' period: from March to September. The Professional Surveys Section of the National Roster tabulated the data and reported the results. It is thought that this survey reveals as accurately as possible the needs of war-related industries for professional and technical personnel. For example, it covered the needs of firms employing, in March of 1943, 114,925 engineers, 20,021 chemists and 1801 physicists. These same firms reported their net needs during the six months' period as, 14,049 engineers, 2331 chemists and 539 physicists. Therefore, the number of additional physicists required in these 15,000 establishments from March to September of last year was 29.9 percent of the number of physicists employed by the same establishments in March. This survey is now being made again, and the employment needs for the first six months of 1944 will soon be available.

The Educational Surveys Section of the National Roster has determined the number of students enrolled in colleges and universities and

* The author, a chemist, is Vice President of the University and Dean of the Faculty. At present he is Chief of the Professional and Technical Division, Bureau of Training, War Manpower Commission.—Editor.

specializing, or majoring, in different critical fields on July 15, 1943. I believe you may be interested in some of the information provided by this survey, although the enrolment situation has changed considerably since that date.

All majors in physics	4497
Men	4090
Women	407
Graduate students	748
Undergraduate students	3749
Men	3403
Women	346
Freshmen	876
Sophomores	887
Juniors	988
Seniors	998

Let us examine the Selective Service status of the male students majoring in physics. Of the total of 4090, we find: 670, or 16.4 percent, classified as I-A; 1873, or 45.8 percent, classified as II; 41, or 1 percent, classified as III; and 242, or 5.9 percent, classified as IV-F. In addition, 476, or 11.6 percent, were under 18 years of age and most of these men were freshmen. Another group of 788, or 19.3 percent, was of unknown status. Many of this group were probably older than 18 but had not yet been classified by the Selective Service System. Some, also, may have been in the process of reclassification at the time the survey was made. It is interesting to note that 670 male students were about to be inducted. This number includes 11 graduate students, 117 seniors and 162 juniors. It is also significant that of the students already classified by the Selective Service System, about 8.2 percent had been placed in the IV-F group.

The National Roster is now collecting similar data from the colleges and universities and will soon be in a position to acquaint us with the situation as it existed in January, 1944. We must anticipate that this survey will show still further decline in the enrolment of student majors in physics. Many men in the present senior and junior classes were deferred before the induction of 18 and 19 year old men began. In the future, if there are no further modifications of deferment policy, only those students who enter training before they are 18, and who can complete sufficient academic work so that they can graduate within 24 months of the time they are certified to Selective Service by the institutions, can be considered for deferment.

Somewhat scanty data lead us to believe that the number of freshmen students that enrolled in technical and professional courses last fall was about 30 percent of the normal number, and that about 30 percent of this number are of such an age that they can later be considered for deferment. If we add to this group the same number of men as are now classified as IV-F and the number of women now enrolled as majors in physics, we arrive at a total of about 1600 students, which can be considered as the maximum number that can be expected to continue training after the current academic year. We must remember, however, that this estimate does not take into account losses due to academic failure. More important still, it does not take into account the probably rather large percentage of able-bodied men who will not wish to be deferred. We cannot look forward, therefore, to anything but an increasingly smaller number of graduates in physics and in other technical and professional fields as well.

There is every reason to believe that the Selective Service System will continue its policy of considering well-qualified physics majors for deferment. There may, of course, be changes in the bulletins dealing with student deferment. These are necessary as the situation changes, but it is my opinion that whatever changes are made will make possible the deferment of as many physics majors as can now be deferred under current policies.

During the academic year of 1942–1943, 1142 persons were graduated with degrees in physics. Of these, 67 received the doctor's degree, 107 the master's degree and 968 the bachelor's degree. What became of them?

Employed in industry	175	15.0%
Entered the armed services	448	39.3%
Entered teaching	209	18.3%
Other employment	310	27.1%

Perhaps you will also be interested in the results of a survey made by the National Roster on the faculty members of departments of physics.

Full-time faculty members employed at close of year 1942–1943	1559
Full-time faculty members as of July 15, 1943	1828
Men	1700
38 or older	871
Under 38	829
Number separated from staffs, May, 1942–July, 1943	465
Number added, May, 1942–July, 1943	1097

Most full-time staff members added during 1942–1943 came from the staffs of other educational institutions or were persons other than physicists but with some training in the subject. The number of nonphysicists added as full-time members was 485. When we add to these the part-time teachers we find that on July 15, 1943, there were 1038 persons other than physicists teaching the subject in the departments of physics in the colleges and universities. Doubtless this number is now much larger, because of the large increase in the number of students that began training in the basic Army Specialized Training Program during the late summer and early fall months.

Of the 1038 substitute teachers mentioned, 211 were recruited from chemistry and chemical engineering, 210 from other branches of engineering, 123 from mathematics, 97 from education, 89 from the biological sciences, 47 from fine arts, music and dramatics, 25 from psychology, 24 from economics and social science, 22 from philosophy, 50 from curriculums leading to general degrees, and 114 from miscellaneous fields. These teachers ranged in age from 18 to 73. Let us give them credit, these teachers who never intended or desired to teach physics. In time of crisis, they have nobly filled a gap in an important battle front, and I am sure that when the job is done and we evaluate their work, the result will not be to their discredit. Perhaps, there are lessons in this experience that may be of value in postwar days.

The situation is still critical. We still need physicists. We need many more than we have or are likely to have. If you were discussing this subject, I should expect you to say something about the way, or a way, of making the situation less critical, and, therefore, I assume that you expect me to have some solution to this problem. But neither you nor I can train physicists overnight or convert from other fields persons who can do much more than teach the elementary phases of the subject. If we could accept the opinion that the war is to end this year, we could forget the whole matter and turn our attention to plans for the peaceful future. But none of us knows with certainty that this war will not continue for many more months, perhaps even years. Not knowing the time when the end is to come, I believe that the only course in the interests of national security is to plan for at least two or three, or maybe even four, more years of strife, of sacrifice, of rationing, of critical manpower shortages—in short, of war and all that it means. If we are to plan for such a war, then in face of the facts concerning the potential supply of physicists, I can only say:

(1) *To the Army and the Navy:* If you see future needs for physicists whom you do not now have in your enlisted and commissioned personnel, set up training programs of your own, now.

(2) *To industry:* If you need physicists, if you need to retain those physicists whom you now have, and if the work that you are doing in support of the war effort demands more physicists than you have, let your needs be known. Tell them to the National Roster; tell them to the Selective Service System; tell them to the War Policy Committee of the American Institute of Physics; tell them to everyone.

(3) *To the colleges and universities:* Attract by every means within your power every potential physics major who has the ability and any desire to become a physicist. Let the students of your institution know of this need and this opportunity. Scan carefully the ranks of women, IV-F men and discharged men who are in school.

And what do I have to say to the physicists themselves? Perhaps I should not say anything at all, because I am less qualified to do so than many who may read this article. However, I should like to make a few comments that have been suggested by a statement that I recently came across in the third report of the War Policy Committee of the American Institute of

Physics, issued December 7, 1942. This statement reads as follows:

> Any investigation of the need for training in physics must take into account the fact that in recent years such training in the United States has been at a very low level as regards numbers and, in many schools and institutions, of low quality as well. We have entered a war making an abnormal demand for physics training with a deficit of such training and with teaching facilities not even adequate for peacetime. Our shortage adds insistence to the desirability of systematically analyzing our needs and establishing a training program of corresponding size and scope.

In order that the situation just described may not again be repeated, it also appears to be desirable—if I may be so bold as to suggest—that we look not only at our needs for the present but for the long-time period ahead of us when war is done and we have turned to peacetime curriculums in our colleges and universities.

I venture the following opinions, therefore, not as a physicist but as a fellow teacher of science:

(1) There should be more students of physics in our colleges and universities. I refer not only to majors in physics but to students majoring in other subjects who should be acquainted with physics, although I am momentarily more concerned with the former. To attract such students, a different sort of freshmen course than that offered in many institutions is desirable and necessary. We must have freshmen before we have seniors, and we must have graduates before we have graduate students.

Of course, some of you will say that you want only the best students, but I can think of several answers to that reply. Why should physics have only the best? Who can tell the best from the mediocre? Are you now getting your due share of the best students? Or are all your students now of the best? And again I hear some one say: Why should we encourage students to specialize in physics when there are so few openings in industry for our graduates? To you, I would say that openings in industry will be as numerous as you physicists make them. Industry must be made aware of the services that physicists can perform. There must be physicists for jobs, and they must fill jobs, before their value is recognized and before there are many jobs to be filled. Not only do demands lead to supplies, but supplies sometimes create demands. Train your men for all kinds of service. Emphasize the cyclotron and nuclear physics not less, but emphasize light and optics, sound, and generators, and galvanometers, and telescopes, and radio more. And what if all physics majors do not get jobs as physicists? Do all graduates in chemistry become chemists? Do all graduates of engineering schools become engineers? Do all graduates in philosophy become philosophers? And do all bachelors of art in history become historians? Are you willing to say that physics is a less desirable field of specialization than government, history of philosophy or study of the drama? Physics is the most fundamental of the sciences, and only physicists can make the world conscious of that fact. Let us have more student majors in physics, and let us study our present course offerings to see what can be done and should be done to increase the number.

(2) A little fairer proportion of our research program in physics should be devoted to the consideration of problems that have direct applications. Let us not be unwilling at least to look at the problems of industry. I do not recommend that theoretical and pure research be neglected. I ask only that both be regarded as within the purpose of our research program, and I do so in order that industry may be made fully aware of the contribution that can be made by physics.

(3) I believe there needs to be a somewhat clearer definition than now exists of the term *physicist.* I think also that there is need for a clear definition of the essentials to be covered by the curriculum in which physicists are trained in our institutions of higher learning.

Man power in physics, today and tomorrow? Today, there is not very much, and there certainly is not enough. Tomorrow, let us have more than enough!

Method of Applying for Emeritus Status in the Association.—Attention is again called to the fact that members of the American Association of Physics Teachers who have reached the age of 60 and have retired from active teaching may, at their request, be given emeritus status and relieved from payment of dues. They will retain all privileges of membership except that of receiving the Journal. These older members, because of their long experience and interest in physics and physics instruction, are in a position to make important contributions to the work of the Association; they are urged to maintain their connections. Applications for emeritus status may be addressed to the Secretary, Professor C. J. Overbeck, Northwestern University, Evanston, Illinois.

Misconceptions in Mathematics and Physics

What Shall We Do About Them?

L. B. Tuckerman
National Bureau of Standards, Washington, District of Columbia

IN starting the recent discussion and listing of "common misconceptions among first-year physics students,"[1] Henry A. Perkins says:

> They originate in outworn notions whose vitality is perennial, in lack of clarity or in positive misstatements in textbooks and in previous faulty instruction.

In his contribution to the discussion, Robert S. Shaw (p. 227) cites the misconception,

> *That* anything in print must be correct.

Unfortunately, this belief is not confined to students but is held, consciously or unconsciously, by many teachers and even writers of text- and reference books. The belief is particularly strong when the outworn notion or positive misstatement appears in a book prepared by a distinguished author or published by a reputable organization. Much of the perennial vitality of many outworn notions comes from the uncritical reproduction in modern text- and reference books of erroneous statements copied bodily or with slight modification from earlier books.

Because of the many serious and even fatal accidents for which it has been responsible, I have been particularly interested in the extraordinary vitality of the misconception that fluctuating or alternating stresses cause metals to "crystallize" and thus become brittle and break. Despite the diligent efforts of many physicists, metallurgists and engineers to lay this ghost, it still walks abroad and is still instrumental in killing people. I have seen it in court records of the testimony of so-called experts in damage suits as late as 1940.

My attention was called to its repetition in a high school textbook on geology in use in 1940. It read:

> Crystallization may even take place in solid noncrystalline bodies. Metals, such as automobile axles or other parts and the steel beams of bridges sometimes undergo this change because of strains put upon the material.

When I wrote to the author, I was referred to Dana's *Text-book of Mineralogy* (ed. 4, revised and enlarged, 1932). In inconspicuous print at the bottom of page 8 and the top of page 9, I found:

> . . . may be in the glass-like amorphous condition. . . . But even in such cases there is a tendency to go over into the crystalline condition. . . . Similarly the steel beams of a railroad bridge may gradually become crystalline and thus lose some of their original strength because of the molecular rearrangement made possible by the vibrations caused by the frequent jar of passing trains.

The passage in the high school textbook evidently is a shortened paraphrase of this passage from Dana, made more vivid to modern youngsters by the introduction of the "automobile axle."

Dana can be excused for writing this in 1898.[2] To be sure, the classic paper of Sorby[3] published 11 years earlier had shown that iron and steel are always crystalline in the solid state and his observations had been amply confirmed by many later investigations. Nevertheless, the belief that the crystalline structure of steel was somehow altered by vibration had not then been disproved and was still current among scientists and engineers.

Only an overcredulous belief in the infallibility of the printed word can account for its retention in the fourth, revised and enlarged edition of 1932, 32 years after the classic work of Ewing and Rosenhain[4] had shown that no perceptible change in the crystalline structure or arrangement of iron and steel ever occurs at ordinary temperatures. Even if the reviser had not seen this work, it is difficult to imagine how he escaped seeing

[1] Am. J. Phys. **11**, 101, 110, 163–165, 227 (1943).

[2] *Textbook of mineralogy* (new edition, entirely rewritten and enlarged, 1898), pp. 6–7.

[3] H. C. Sorby, "On the microscopical structure of iron and steel," J. Iron and Steel Inst. **1**, 202–288 (1887).

[4] J. A. Ewing and W. Rosenhain, "The crystalline structure of metals," Phil. Trans. Roy. Soc. **A193**, 353–372 (1900).

some of the voluminous later literature on the subject.

I am thankful that this statement has been deleted from the later reprintings of the fourth edition of Dana, but that will not undo the harm it has already done.

When some college professors are thus credulous and have uncritical faith in some printed words, we can hardly expect all grade and high school teachers to be more critical and less credulous. For that reason it is particularly harmful when a supposedly reliable reference book especially intended for teachers in the grade and high schools is crammed with misinformation. It is sure to result in many further misstatements in textbooks and in much faulty instruction.

A very favorable review recently led me to read a publication entitled, *A Source Book of Mathematical Applications*.[5] According to the editor's preface, it is "the seventeenth of the series of Yearbooks started in 1926 by the National Council of Teachers of Mathematics" and "represents a most important addition to the volumes that precede it." In the introduction to the book it is stated that:

> To help meet the need for a broader knowledge of direct application, this volume has been prepared as a reference book for teachers of the mathematics usually offered in grades seven through twelve. It may also prove useful to students in teacher-training institutions and to others who are interested in discovering how the principles of mathematics are being employed in solving the world's problems.

After reading this eulogistic introduction, I was amazed to find how much misinformation the book contains. It abounds in grossly careless proofreading which completely distorts the meaning of sentences, in careless checking of references leading to printing absurd numerical values, in confusion of physical units, in absurdly sloppy statements, and even in sheer asininities.

There follow, as illustrations, a list of a few excerpts from this book. Many more could be given. In line with the lists already published,[1] we might call this list and much of the rest of the contents of the book, "a forecast of physical misinformation among school mathematics teachers and their students."

[5] Bureau of Publications, Teachers College, Columbia University, 1942.

6.12. DAILY LIFE. . . . The letter left a Texas airport at 1:05 P.M. and arrived in New York at 2:55 A.M. How long did it take to get there? Solution:

11:60
$\cancel{1}2:\cancel{0}\cancel{0}$ P.M.
−1:05 P.M.

10:55 = 10 hr. 55 min.

10 hr. 55 min.
+2 hr. 55 min.

12 hr. 110 min. = 13 hr. 50 min. [p. 17]

6.19. HOUSEWIFE. Every standard electric sweeper or iron is tagged with a plate upon which is stated the number of watts that are consumed by the machine in one hour. [p. 19]

10.01. AVIATION. . . .

3. To change miles per hour to knots (one knot equals a speed of one nautical mile per hour) per hour, multiply by 7/8.

4. To change knots per hour to miles per hour, multiply by 8/7. [p. 21]

21.04. DAILY LIFE. A geographic mile is the length of one minute of arc on a great circle of the earth. [p. 87]

13.02. GEOGRAPHY. . . . A nautical mile (geographical mile or knot) is the length of one minute of arc of a great circle of the earth. [p. 188]

11.09. AUTOMOBILES. . . . Thus, in foot-pounds,

$$\text{Force of crash} = \frac{mv^2}{64}. \text{ [p. 32]}$$

16.31. PHOTOGRAPHY. Camera shutter adjustments are marked $f4$, $f6.3$, $f8$, etc. These f markings are known as the focal ratios. They are the ratios between the focal distance of the camera and the areas of diaphragm openings. [p. 62]

19.15. ENGINEERING. . . . The efficiency of a machine is that part of the power supplied to it that the machine delivers. . . . (c) The efficiency of a gas engine is around 80%, while the efficiency of a steam engine is generally a little better than 90%. [p. 73]

1.99. PHYSICS. The number of degrees, T, which the sun loses in heat for every t million years is $T = 12{,}000e^{-.0868t}$. [p. 121]

7.17. PHOTOGRAPHY. In projecting pictures the brightness, b, of the projecting light varies directly as the distance, d, of the desired projection, i.e., $b = kd$. [p. 143]

3.09. DAILY LIFE. When a light ray passes from a less dense to a more dense medium, its path is deflected. The amount of deflection is called the angle of refraction, which is determined for various transparent mediums. [p. 149]

4.03. ASTRONOMY. Twilight lasts until the sun is 18° below the horizon. From this find the height of the atmosphere. [p. 222]

It would be difficult to exaggerate the harm that this book can do in the hands of the average grade or secondary school teacher. I showed my list of excerpts to a college graduate who is now doing excellent work as a computer but who hopes to teach high school mathematics after the war. To my astonishment, she expressed the opinion that the items were excellent and would be of great help to teachers. After I had pointed out the defects, she explained that she had not studied physics in college and of course could not be expected to recognize their absurdity.

Students experience enough difficulty with mathematics as it ordinarily is given in schools without being further confused with the "broader knowledge of direct applications" which this book presents. In my opinion the best service the National Council of Teachers of Mathematics and the Teachers College of Columbia University could at present render to the teaching of mathematics would be to call in all the copies of this seventeenth Yearbook and destroy them.[6] It is, of course, too late to prevent some harm being done, but at least that would diminish its future noxiousness.

All this raises the question what, if anything, the American Association of Physics Teachers and other national scientific and technical organizations can and ought to do to lessen the current flood of "positive misstatements in textbooks [and reference books]." Merely to end a mildly critical review of such a book as this with the statement, "This book should not be used by any teacher who lacks a working knowledge of physics"[7] will not prevent its use by many teachers who do lack "a working knowledge of physics." Merely to publish lists of current misconceptions, although it will help teachers by letting them know what to anticipate, is somewhat like locking the barn after the horse is stolen. To be really effective, some concerted effort must be made to prevent their appearance in texts and reference books. It would be of interest to have Professor Perkins publish an analysis of the results of his course of five or six lectures at Trinity College. If it was reasonably effective, an outline of his lectures might be useful in showing others how they could help in lessening the plague.

The misconception about the "crystallization" of metals mentioned earlier had such serious consequences for aviation that the Bureau of Aeronautics of the Navy Department requested the cooperation of the National Research Council in its efforts to disseminate accurate information instead of misinformation among "designers, machine shop superintendents and workmen, inspectors and others having to do with the design, construction and servicing of aircraft." Out of this came a handbook, *Prevention of the Failure of Metals under Repeated Stress*,[8] of which 500 copies were distributed by the Bureau of Aeronautics to manufacturers and naval officers and employees. This has helped.

Some of us make it a point, whenever we see this misconception in print, to write to the author or publisher giving him a correct statement of the facts and calling his attention to the harm he is doing by helping to perpetuate the misconception. These efforts also have materially helped the situation. Fewer men today use "crystallization" as an alibi for an accident caused by their carelessness or flagrant violation in design, workmanship or inspection, of the fundamental principles of prevention of failure under repeated stress. It is, however, a Sisyphean task that is laid upon us. Again and again I think of the words of the Rabbi Tarphon,

> It is not given thee to complete the work.
> Neither art thou free to desist from doing it.

Thinking again over the dozens of fatal accidents, ascribable at least in part to this one misconception, about which I have been consulted, I have wondered how many of the misconceptions pointed out in the lists in this journal[1] and the blunders in the Yearbook[5] might have

[6] Because of a comment by a reader to whom I showed a preliminary draft of this article, I wish to make it perfectly plain that this opinion applies solely to the seventeenth Yearbook. I am assured by competent teachers of mathematics and physics that others of this series of Yearbooks have deservedly high reputations. I have had opportunity to glance through only two of the latter, the fifteenth and sixteenth; even a cursory reading convinced me that every teacher of school mathematics and physics should own them and study them carefully.

[7] Am. Math. Mo. **50**, 510 (1943).

[8] Prepared for the Bureau of Aeronautics, Navy Department, by the Staff of Battelle Memorial Institute under the auspices of the National Research Council of the National Academy of Sciences (Wiley, 1941).

equally dangerous consequences. Two come readily to mind. One is the belief[9]

That "volts go through a man who is electrocuted."

While I was teaching electrical engineering students many years ago I was twice called as an expert witness to explain to a jury how it could happen that a man could be "killed by 110 volts." I think it can safely be said that the belief that electrocution requires a high voltage has been responsible for hundreds of "bath tub" deaths.

The other is the belief[10]

That extrapolation and interpolation are equally valid processes.

Some of the worst engineering catastrophes have been a direct result of an undue faith in extrapolation beyond existing data. As illustrations I may cite two cases that come to mind, the Quebec Bridge and the Tacoma Narrows Bridge. A search through engineering literature would show dozens of others.

Even if some of them are mere nuisances rather than positive dangers, I hate to think how many times the misstatements and misconceptions printed in the Yearbook will, like the passage from Dana, be quoted, copied and paraphrased by many teachers in the grade and high schools and in other text- and reference books prepared for their use. I hate to think of the many teachers who will accept them as Gospel truth merely because they have been printed. I hate to see them adding thousands upon thousands to that already too numerous horde of students who "never could understand mathematics," because they never could swallow the nonsense which their teachers insisted they must.

Although individually the harm these misstatements and misconceptions can do may be slight, in the aggregate it is enormous. I have no specific suggestions to make, but I feel strongly that there rests upon the American Association of Physics Teachers and other national scientific and technical organizations an obligation to do their best to ensure that the text- and reference books placed in the hands of teachers and students are so far as possible free from misstatements and misconceptions.

[9] Reference 1, p. 102.
[10] Reference 1, p. 164.

Physics at the United States Military Academy

B. W. Bartlett*
United States Military Academy, West Point, New York

THE belief that physics teachers all over the nation who have been struggling with the problems of maintaining and increasing staffs and equipment to cope with ASTP, V-12, AAF Premeteorology and similar programs will find something of interest in West Point methods has led to the preparation of this article. The war has brought changes even at the Military Academy, so I shall describe both the normal operation of the department and the modifications required because of the tremendous expansion of the military establishment as a whole. Being neither a peacetime member of the Military Academy Physics Department nor a Regular Army officer, I shall hope to bring an objective point of view to my task. (In all fairness, however, it should be recorded that I am myself a graduate of West Point of the World War I vintage.)

The physics department at West Point differs from that at an ordinary college, university or engineering school in that it conducts only a general elementary physics course. Such intermediate physics as is included in the curriculum is handled by the Departments of Chemistry and Electricity and of Mechanics. The work of these departments is conducted primarily from the engineering standpoint, so that the situation here resembles that in many engineering schools, in which all engineering students are required to take a basic course in physics before starting their engineering work proper.

* Colonel, A.U.S., on leave of absence from Bowdoin College.

Historically the physics department is the youngest of the departments of instruction at West Point, having been established as a separate entity only in 1931. Prior to 1931 the subject matter now taught as physics was divided between the Department of Mechanics (then named the Department of Natural and Experimental Philosophy) and the Department of Chemistry and Electricity. Mechanics, sound and light were included under the former, and heat and electricity and magnetism under the latter. At the time of its inception the new Department of Physics acquired from these departments most of the laboratory and demonstration apparatus formerly used in teaching elementary mechanics, sound, heat and light. On the other hand, in the fields of electricity and magnetism and of modern physics the new department had to start from scratch.

PHYSICS CURRICULUM

In the regular four-year Military Academy course physics is a second-year (sophomore) subject, the entire class being required to attend three times a week throughout the period from September 1 to June 4, except for a ten-day break at Christmas. The 114 class periods available are used as follows:

Regular recitations of 80 min	70
Written general reviews (examinations), 80 min each	20*
Laboratory periods, 120 min each	18
Lectures, 80 min each	6
Total meetings of class	114.

Of the total time at the department's disposal, 35 percent is allotted to mechanics, 8 percent to sound, 14 percent to heat, 27 percent to electricity and magnetism, and 16 percent to light, the order being chronological.

The physics course in the "yearling" (sophomore) year is followed in the junior year by full-year courses with daily attendance in the Departments of Mechanics and of Chemistry and Electricity. In the former the cadet studies analytic mechanics (64 attendances), strength of materials (45 attendances), engineering thermodynamics (53 attendances) and fluid mechanics (50 attendances), 25 of the total attendances being laboratory periods in thermodynamics and fluid mechanics. In the latter, in addition to chemistry, he has 105 recitations and 25 laboratory periods in electrical engineering. Although these two third-year courses are taught from the engineering point of view, the work in analytic mechanics and thermodynamics covers considerable material often taught in intermediate physics courses, and some of the subject matter in the electrical engineering course is not dissimilar to the content of the writer's second-year course in electricity and magnetism offered at Bowdoin College some years ago.

For the duration of the war the Military Academy course has been shortened to three years, but very wisely the time allotted to the basic physics course has been left substantially unchanged. About half the "yearling" class leaves West Point to take primary flying training in the middle of April, thereby losing some 20 class periods. The expedient of putting the laboratory work and the written general review lessons in heat, electricity and light at the end of the course has made it possible to cover all the advanced work by the time the "air cadets" leave. The engineering departments have not been so fortunate, as the number of periods assigned to them has had to be curtailed by about 25 percent.

THE STUDENTS

An Academy policy of very long standing has been to require all cadets to undergo the same training regardless of educational background. Under peacetime conditions the entire "yearling" class of approximately 500 cadets takes the basic physics course annually. All of these men have had mathematics daily during the academic portion of their "plebe" (first) year. The first-year mathematics course includes solid geometry, college algebra, plane and spherical trigonometry, and analytic geometry. In the "yearling" year, for three periods a week concurrently with the physics course, the class studies differential and integral calculus, followed by a brief introduction to ordinary differential equations and some work in statistics. The physics instructor can accordingly presuppose that all his students are reasonably proficient in the mathematics required in the usual general physics course of collegiate

* Includes five *Cooperative Physics Tests*.

TABLE I. Class of 1945, 884 men.

General preparation	Percent
Cadets who entered direct from high school	28
Cadets who entered from preparatory school or junior college	22
Cadets who had completed one to three years of college	47
College graduates	3
Preparation in physics	**Percent**
Cadets who had never studied physics before	15
Cadets who had had secondary school physics only	64
Cadets who had had one year of college physics	18
Cadets who had had more than one year of college physics	3

grade. (In passing I might remark that even so thorough a college mathematics course as that given at the Military Academy cannot and does not entirely compensate for the failure of grade and secondary schools in many places all over the United States to teach our children the basic processes of arithmetic.)

At this point the uniformity in preparation ceases. The backgrounds of the cadets are considerably more heterogeneous than one normally encounters in students beginning a college or university physics course. A college graduate who has majored in physics may occupy the seat next to a boy who entered West Point from a small high school without even a secondary school physics course behind him. As a sample of this wide discrepancy in preparation I quote in Table I some statistics of the present "yearling" class (admitted to the Academy in the summer of 1942). Similar surveys conducted by others in the past 10 years have yielded comparable figures, so that the sampling in Table I is representative of normal conditions. Any study of student accomplishment at the end of the West Point physics course must obviously take into consideration the fact that about 20 percent of the cadets have previously had a college course in physics.

TEACHING METHODS

The teaching methods in all subjects in the West Point curriculum are strongly influenced by certain fixed policies dictated both by regulation and by long-established custom. Running the usual risks incident to generalization, one may say that all of these policies are aimed at carrying out the single fundamental principle that *learning by doing is more valuable than learning by precept.* In other words they all tend to emphasize the work of the student and to minimize the importance of the individual instructor. To this end the following specific devices are used:

(1) Classes are normally limited to 15 cadets; that is, if 500 cadets were taking physics, they would be divided into 34 sections.

(2) Each cadet is required to recite (in physics to solve problems at the blackboard) at each class meeting, and is graded on his work.

(3) Cadets are sectioned according to ability in the subject, so that all the men in a section have about the same class standing.

(4) Instructors are rotated among the sections monthly, so that each cadet normally has several different instructors in each subject.

(5) The assignment of cadets to sections is revised monthly, and any individual may go to a higher or a lower section according to his record during the preceding month.

(6) Grades are published weekly, and the relative standing of the whole class in each subject monthly.

The physics department operates within this general framework in the following manner. At each recitation the instructor spends about 40 min in answering questions, emphasizing the more important points in the lesson and performing lecture-table demonstrations. An attempt is made to have some demonstration apparatus available for and used at every meeting of the class. At the end of the demonstration period the entire class is sent to the blackboards for about half an hour to do problems on the lesson. Some of the problems will previously have been assigned for home study, while some will be new to the cadets. Use of the slide rule is required. During the problem period one or two cadets are normally required to make formal recitations upon assigned topics. This practice is common to all departments, and is very valuable in training the embryo officer to be articulate before an audience. At the end of the problem period the instructor displays approved solutions of the problems, and allows 5 to 10 min for questions. After the section has been dismissed the instructor grades the boards and records the grade of each man. Each cadet is issued a departmental problem pamphlet containing 2000 problems, some original with the department, but for the

most part selected from standard college physics textbooks. The conduct of the classes is very informal, the cadets being urged to ask questions and participate freely in discussion. Any cadet who feels he has not mastered the day's lesson may ask for and receive an hour of extra instruction during his free time in the late afternoon. Instructors are assigned by roster to give the extra instruction to groups of not over 10 cadets.

About every fourth recitation is in the form of a written review of the lessons covered since the preceding review. The full length of the period is used for these reviews, which correspond roughly to what are often called "hour examinations" in the colleges, except that in the computation of averages they receive no more weight than any other lesson. At the end of each term, in lieu of the final examination customary in college circles, a series of "written general reviews" is held. Each lasts one full period, there being six at the end of the fall term, just before Christmas, and nine at the end of the spring term, in June. The "written general reviews" are each given double the value of a single recitation in the computation of final standings. Any cadet whose average grade is below passing ($66\frac{2}{3}$ percent) at the end of the term is required to take a four-hour final examination, failure in which carries the liability of dismissal from the Academy.

Eighteen 2-hr laboratory periods are interspersed throughout the year. Each cadet is required to prepare and bring to class a preliminary report on the experiment he will perform. During the laboratory period he completes one or more experiments, and turns in a report on each. Because of the limited time available (all the men have to be dismissed promptly at the end of the period) the reports are made on printed forms which reduce the writing on the part of the student to a minimum. With a few exceptions standard commercial laboratory apparatus is used for the 25 experiments performed. The range of these exercises is similar to that of the laboratory work in any standard college physics course.

At the end of the spring term the upper half of the class is excused from the "written general reviews" and in their place is given a dozen advanced lessons in modern physics. The work consists of textbook assignments amplified by informal lectures by the instructors. To satisfy the grading regulations of the Academy, in place of problem work the class is given a brief multiple-choice quiz daily. This year the same sort of arrangement was tried experimentally at the end of the fall term, the upper quarter of the class

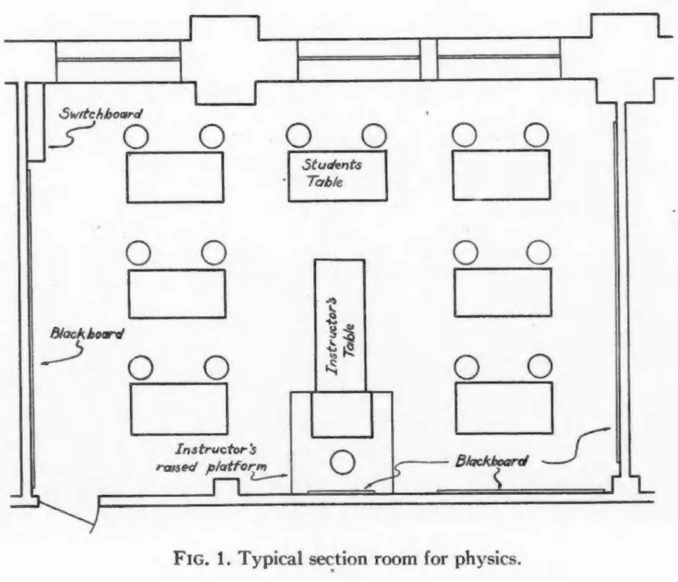

FIG. 1. Typical section room for physics.

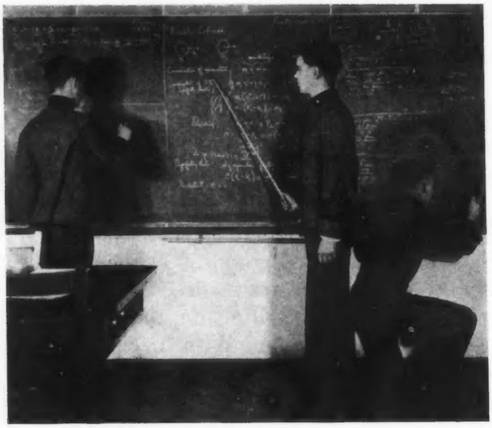

FIG. 2. A recitation and problem work.

taking six lessons in vector mechanics instead of the reviews.

Because of increased enrolment and the elimination of one class in the three-year course, some modifications in the methods outlined have been necessary. The only significant change has been an increase in the size of the sections from 15 to 21 men, occasioned by a jump in the size of the "yearling" class from 500 to 900 men for the academic years 1943–44 and 1944–45. Faced with the choice between keeping the sections small and using extra classrooms not suitably equipped, and holding to the standard equipment by increasing the section size, the department followed the latter alternative. It is too early to evaluate the effects of this change.

PHYSICAL PLANT

In the fall of 1938 an entire new wing of the East Academic Building at West Point was completed. Sufficient space in it was assigned to the physics department to provide, among other things, 11 classrooms completely equipped for instruction in physics. A typical room is 26×36 ft in plan. Slate blackboards on the walls provide 15 panels, 42 in. wide and 45 in. high, for cadet problem work and an additional panel for the instructor with a curtain for covering it when desired. Seven fixed laboratory tables, each 69×36 in. on top, are provided for cadet use, and a larger demonstration table, 96×36 in., for the

FIG. 3. A laboratory period.

instructor. The arrangement is shown in plan in Fig. 1. The student tables are designed to serve as desks at ordinary recitations. All the tables have built-in drawers and cabinets underneath them, storage space being thus provided to accommodate almost all the demonstration apparatus used in the section throughout the course. The student table tops are of acid-resistant compressed wood fiber; the top of the instructor's table, of acid-resistant stone composition. A covered recess in the top of each table contains a panel with two sets of electric outlets, each set being fed by a separate circuit from a slate distribution panel in one corner of the room. On the main panel are available 110-v a.c. and d.c., 220-v d.c., and storage battery connections up to 24 v in units of 4 v. A 15-ohm rheostat can be placed in series with any of these circuits at the distributing panel. All the tables are provided with gas outlets. In addition, the instructor's table has an inset soapstone sink with hot and cold water which can be covered when not in use. Each table also has set flush with its top two threaded aluminum receptacles into which $\frac{3}{4}$-in. metal rods can be screwed to act as supports for apparatus.

Each classroom contains a complete set of demonstration apparatus, identical from one room to the next, a situation highly to be desired because of the monthly shifting of instructors among the sections. The apparatus included in the section room set is adequate for performing most of the demonstrations presented in a first-class general college physics course. With some exceptions it is all standard equipment purchased from commercial laboratory supply houses. Such lacunae as now exist in it are being filled systematically by purchases from annual appropriations. Each room has a projection lantern, wall screen and window shades to go with the rest of the demonstration equipment. Any teacher of college physics should be delighted to have such a classroom and its equipment at his disposal. In addition to the multiple sets of demonstration apparatus, use is made of a considerable number of pieces too large or too expensive to be repeated 11 times. Such items are made available on rolling carts and passed from one section room to another during the course of the recitation period. Representative of this category are cathode-ray oscillographs, hydraulic presses, Hyvac pumps, a Tesla coil and numerous pieces of modern physics apparatus. Figures 2–4 show a section room being put to some of its uses.

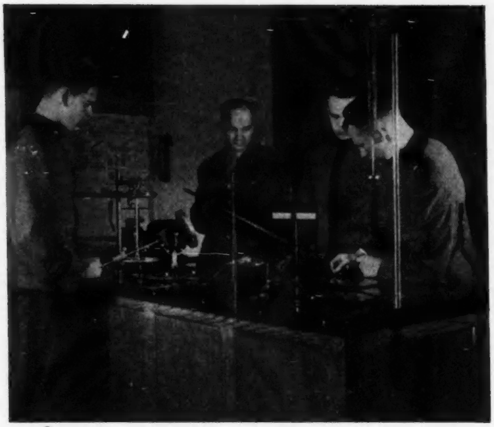

FIG. 4. A classroom demonstration.

An appreciable amount of apparatus, largely of historical interest, was inherited from the old Department of Natural and Experimental Philosophy. In particular, there are several score pieces of demonstration apparatus in mechanics, hydrostatics, "pneumatics" and optics imported from Paris and London between 1829 and 1844, all listed on the inventory of 1844 preserved in the department. Several large spectrometers, saccharimeters, a compound microscope and a great

FIG. 5. Iceland spar rhomb. The numeral 1 is $\frac{3}{4}$ in. high.

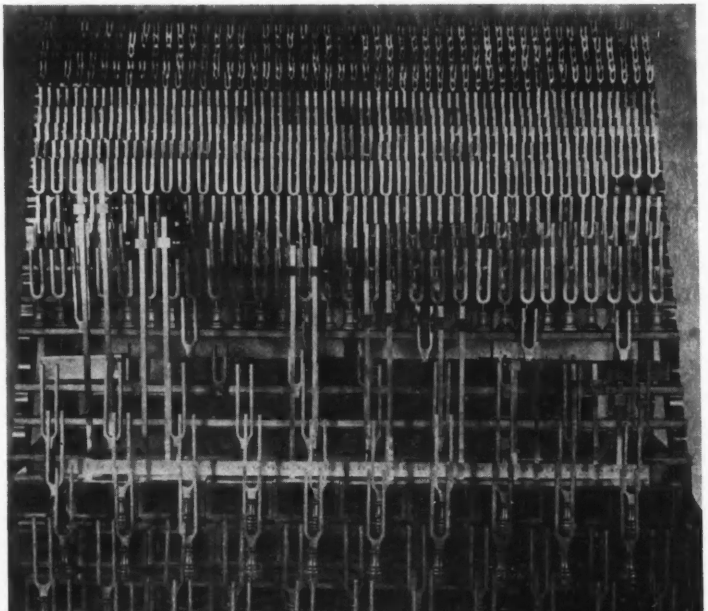

FIG. 6. The Koenig tuning fork collection.

variety of specimens of uniaxial and biaxial crystals appear to have been imported during the second half of the nineteenth century. Among the latter are several very fine rhombs of Iceland spar having dimensions of the order of 2 in. on a side, one of which is shown in Fig. 5. The most impressive among the historical items is a remarkable collection of tuning forks (Fig. 6) manufactured by Rudolf Koenig in Paris and brought to this country for display at the International Exhibition in Philadelphia in 1876. The collection, along with numerous organ pipes and resonators of various types, was acquired by the Academy after the exhibition was over. The following quotation from the official report[1] on the exhibition serves as a good description of the set:

> In the construction of apparatus of precision for purposes of research or demonstration in acoustics, the very ingenious optical methods for the analysis of musical sounds by means of manometric flames were devised by Dr. Koenig in 1862, and have since been greatly improved by him and applied also to the study of the phenomena of interference. More recently he has made a very elaborate investigation of the nature and causes of the resultant sounds heard when two notes of different pitch are sounded together, and has shown that even very eminent investigators have been in error in their views of these phenomena.
>
> In the present exhibition Dr. Koenig has presented a collection of instruments of demonstration and investigation constructed on a scale of magnitude heretofore unattempted, and exhibiting with surprising power the effects of interfering undulations.

[1] *U. S. International Exhibitions, 1876* (Govt. Printing Office, 1880), vol. VII.

He also presents a tonometric apparatus, consisting of about six hundred and seventy diapasons, or tuning-forks, giving as many different shades of pitch extending over four complete octaves, and making equal intervals of eight simple vibrations each for the first octave, and of twelve each for the succeeding octaves; the whole forming an absolutely perfect means of testing, by count of beats, the number of vibrations producing any given musical sound, and of accurately tuning any musical instrument.

In addition to these more conspicuous portions of his display, Dr. Koenig exhibits the various forms of apparatus of demonstration for which he is so well known, all of which are marked by the accuracy of indications and excellence of workmanship which have given him his deserved reputation as a constructor. One instrument of novel character, not yet fully completed, and exhibited only as an untested project, promises too interesting results to be overlooked in this report. It is a multiple sirene, designed to produce synthetically the various qualities of musical sound by the combination of overtones with the fundamental, and also to exhibit the effects of varying phase in the formation of such combinations. Of the exhibit of Dr. Koenig, as a whole, it may be said that there is no other in the present International Exhibition which surpasses it in scientific interest.

The department has a well-equipped machine shop with a full-time instrument maker available for the repair and maintenance of its equipment. The office space consists of one large room for the teaching staff, a separate office for the professor and the department library, and another for the department clerk and stenographer. Three large storerooms serve to house the scientific equipment not kept in the classrooms, and the department is furnished an enlisted technician to assist in caring for it and setting it up for section room use.

INSTRUCTIONAL STAFF

The peacetime organization of the department calls for one professor, one assistant professor and about ten instructors. The professor has permanent tenure, being appointed by the President of the United States with the military rank of lieutenant colonel. Upon the completion of ten years' service he is promoted to colonel. He is the head of the department and has a seat on the Academic Board of the Military Academy. His freedom in the administration of his department is limited by the regulations of the Academy. For example, the general outline of his course and the textbooks used in it are subject to the approval of the Academic Board. In practice this limitation is more formal than actual. The professor does no teaching, except for occasional lectures to the whole class. He does, however, make frequent visits to the section rooms to observe the instruction taking place, thus keeping in close touch with the progress of the cadets and the methods of his instructors. In a very general way one may say that the professor handles all extra-departmental relationships of the department, and lays down the directive policies for its internal administration, these policies being put into execution by the assistant professor.

To understand the West Point Professor of Physics and his predecessors, the Professors of Natural and Experimental Philosophy, one must realize that his primary duties are administrative and pedagogic. Being the one permanent member of the department, it is his job to be himself thoroughly familiar with the field covered by his subject, and—what is equally important—to see to it that the material he decides should be imparted to the cadets is presented to them in the best possible manner by the instructors who are actually to do the teaching. He has the task of selecting his instructors and making sure they are properly trained. In addition, a large portion of his time is occupied by committee work and general administrative problems outside his own department. Under these circumstances one would rarely find the West Point professor engaged in fundamental research of the type expected of faculty members of professorial status in the large universities, and in fact I doubt that such activity would be particularly desirable at so specialized an institution.

In the past many of the professors in the physical science departments have written excellent and widely used textbooks. William H. C. Bartlett, Professor of Natural and Experimental Philosophy from 1834 to 1871, and a member of the National Academy of Sciences, was author of texts on mechanics, optics, acoustics and astronomy. Peter S. Michie, William B. Gordon and Clifton C. Carter, who occupied the same chair successively down to the present time, each wrote one or more textbooks. As a cadet the writer studied electricity from the book written by Wirt Robinson, the then Professor of Chemistry and Electricity, and heat and chemistry from

the books of General Samuel E. Tillman, Robinson's predecessor in the department. In retrospect I feel that Robinson's *Elements of Electricity* is an unusually fine example of clarity in textbook diction, and I often refer to it for pedagogic purposes. With the exception of the first Professor of Natural and Experimental Philosophy, Jared Mansfield, a graduate of Yale University, all these men were trained as Regular Army officers and were graduates of West Point. The biographical records available to me indicate that they were men in whom scholarly interests and administrative ability were combined to a rare degree. Certainly this statement applies in the case of the few of them whom I have had the good fortune to know personally.

The present incumbent of the chair of physics is Colonel Gerald A. Counts. Colonel (then Captain) Counts was appointed Acting Professor of Physics at the birth of the new department in 1931, and has been its head ever since, the acting appointment having been made permanent in 1934. Colonel Counts entered West Point as a cadet in the summer of 1914, after having completed a year at the University of California. He was graduated second in his class at the Military Academy in August, 1917, a year early because of the exigencies of World War I. He served in France during the war, rising to the grade of captain in the Corps of Engineers. After the war he was sent to Massachusetts Institute of Technology for a year, receiving the degree of B.S. in Civil Engineering in 1921. During the next decade he served tours of duty in the offices of the District Engineers in Los Angeles and in Galveston, at West Point as instructor and assistant professor in the Department of Mathematics, and spent a year in graduate study in mathematics and physics at the California Institute of Technology. Since August, 1943 he has been absent from West Point on extended temporary duty in the North African Theater, the writer being acting professor during his absence. Any comment by the writer on the abilities of Colonel Counts would be not only presumptuous, but superfluous as well, since most of this paper is concerned with the description and evaluation of the department under his administration.

The remainder of the instructional staff is normally composed of Regular Army officers—almost always graduates of West Point—detailed to the Academy for four-year tours of duty. The senior instructor is normally the assistant professor, holding the position after two or more years of experience as an instructor. As assistant professor he teaches only when one of the instructors is absent because of illness or some other emergency. He handles the internal administration of the department, including the education of new instructors, the coordination of instruction, the preparation of written recitations and examinations, the care of the property and similar administrative tasks. Very often he will have had a previous tour of duty as an instructor in this or an allied department, and is usually a man of maturity and experience.

The instructors are ordinarily a carefully selected group of younger graduates of West Point, chosen both for their proficiency in the subject of physics and for those personal qualifications usually considered requisite for a good teacher. Except in time of national emergency no officer is brought back as an instructor until at least four years have elapsed since his class was graduated from the Academy. This regulation insures that none of the instructors will be teaching a cadet who was an undergraduate while he was himself in the Corps of Cadets. While the educational histories of a typical group of instructors will vary somewhat, many of them will have attended college before entering West Point, and most of them will have attended either army service schools or civilian universities for postgraduate work in some technical field. Most of the branches of the service—engineers, signal corps, ordnance, artillery, and so forth—will be represented among them.

The new instructor ordinarily reports early in June and spends his first summer in preparation for the coming academic year. Under the supervision of the assistant professor he works out solutions of all the problems he will use during the year, observes all the demonstrations and performs the laboratory experiments. During his first year as an instructor he is not assigned any military duties, so that he can devote his entire energies to his academic work. His teaching load is two 80-min periods six days a week. Actually the schedule is so constituted that he teaches the same lesson two days in succession, so that he has

only three advance lessons a week to prepare. After his first year an instructor is required to assist in the military training of the cadets, on the average one or two afternoons a week during the academic year, and to devote a part, at least, of each summer to the field instruction of the cadets. Selected instructors may be sent to do graduate work in physics at nearby universities during the summer recess or in the evening during the regular term.

Since the declaration of war it has been the policy of the Academy to replace at least half of the Regular Army officers in each department by qualified reserve or retired officers, or by the commissioning of specialists directly from civilian life. The physics department has been fortunate in being able to secure very competent people in these categories. The newcomers include two retired officers, three West Point graduates who had entered civilian life and were recommissioned for the duration, a National Guard officer, an R.O.T.C. graduate and a civil engineer commissioned as a specialist. Of the eight emergency instructors, one has a Ph.D. in physics, two have completed considerable work toward their doctorates, and three hold master's degrees. The fact that few of the new men had had previous experience in teaching college physics caused no particular difficulty, because all of them had sufficient background to assimilate the regular instructor training program readily.

RESULTS OF THE WEST POINT METHOD

An evaluation of the effectiveness of the West Point Department of Physics should take into account its objective, or mission, to use the military term. Because the Military Academy itself serves a highly specialized purpose, it is to be expected that the mission of the physics department will be different from that of an ordinary college or university department. Most of the latter perform many functions: research in pure physics; the training of research workers; the training of college physics teachers; the training of secondary school physics teachers; the development of improved pedagogic methods; the preprofessional training of engineers, medical students and the like; the dissemination of a cultural knowledge of physics as widely as possible among the educated public, insofar as the graduates of our colleges and universities constitute the educated public. The mission of the West Point department is to give each cadet the basic working knowledge of general physics required for his successful completion of the engineering studies in the curriculum, and in addition an appreciation of the subject sufficiently fundamental to enable him to make intelligent use of the innumerable practical applications of the physical sciences found in modern warfare. Its function is essentially the same as that of the division of an engineering school or university physics department engaged in pre-engineering physics.

Because the department has been organized directly and specifically to carry out this particular mission it is obvious that some of the important activities of a university physics department can in the nature of things be given little or no attention. The opportunity for pure research is practically nonexistent, and quite properly so. Neither the technical facilities, the trained personnel nor the requisite atmosphere could be made available without an unauthorized expenditure of government funds. At the level of cadet instruction any attempt to train research workers would be silly. Except in the sense that the department gives training to its new instructors there is no thought given to the education of teachers.

What the department is primarily concerned with is that the maximum possible number of cadets acquire a thorough practical working knowledge of general physics. As a corollary it is also preoccupied with improving and developing its methods of presentation of the subject. Constant search is made for new and better demonstration and laboratory apparatus. The choice of textbook is carefully reviewed each year. Instructors are encouraged to initiate improvements in their teaching techniques. They are expected to read the numerous technical and semipopular periodicals subscribed to by the department for the purpose of finding up-to-date illustrative material. A rivalry has been developed in the devising of original problems for use in the section room and on the written recitations.

The mission of the department having been defined, it is appropriate to assess its success in accomplishing it. Unfortunately it is extremely

difficult to establish valid objective criteria of teaching efficiency. Four methods of evaluating the accomplishment of the cadets in general physics occur to me as reasonable: (1) the success of cadets in subsequent work that builds upon a knowledge of physics; (2) a comparison of the questions on the written recitations with typical quiz and examination questions in other physics courses; (3) the achievement of the cadets as measured by their scores on the *Cooperative Physics Tests;* (4) the judgment of individuals with teaching experience elsewhere who have actually taught cadet classes here.

Applying the first method one finds that the records of West Point graduates who have attended graduate and engineering schools in those technical fields which are really applied physics have been uniformly excellent. This is attested both by actual grades and by many comments, written and oral, from professors at such schools. This evidence obviously is not conclusive taken by itself, for it is conceivable that deficiences in the physics course are subsequently corrected in other departments. The testimony of the engineering departments, however, tends to substantiate that of the civilian schools. In particular, chemistry is this year being taught concurrently with physics, whereas it has always previously followed the physics course. The Professor of Chemistry tells me that the effect upon his course this year is striking, requiring changes in his method of presentation to offset the lack of physics preparation in this year's class.

Copies of the written recitation questions and the class averages obtained upon them since the inception of the department have been kept in its files. I have been greatly impressed with the level of difficulty of the problems which the cadets are expected to master, and with the extent to which they succeed on the average. Not infrequently problems that the writer would have found appropriate for an intermediate rather than an elementary course are set for the written recitations.

The college physics tests of the Cooperative Test Service were given the entire class at West Point in the academic year 1939–40 and again in 1942–43. The results in 1939–40 were extraordinarily good. The 50-percentile score in mechanics, heat and sound was 52, as compared with national values of 40 for engineering school students and 37 for male college general physics students. In light and electricity the 50-percentiles were 31 for the cadets, 28 for engineering students and 25 for male college students. In other words, half the cadets did better than 72 percent of the engineering students and 77 percent of the general college students in mechanics, heat and sound, and better than 60 percent of the engineering students and 65 percent of the general college students in light and electricity.

In making these comparisons one must of course remember that about 20 percent of the cadets had previously had a college course in physics. The scores were so kept that the records of men who had had college physics, high school physics and no physics could be segregated. In mechanics, heat and sound the median scores were 58, 52 and 45 for the three groups, respectively. Actually, the numbers in the first and third categories were about equal, so that the median for those who had had high school physics was identical with the median of the whole class. Since high school physics is a prerequisite for entrance to many engineering schools, and since even when it is not most engineering school candidates will have taken it from choice, it appears that the effect of those who have had college physics can be discounted in comparing the results of the West Point course with the engineering school averages.

A point to be considered is the fact that these tests do not necessarily measure ability to solve problems. My personal feeling is that a quarter to a third of the men who are good at the formal solution of problems do not show up well on the multiple-choice type of test. I believe that the training in the solution of problems which is a high point in the Military Academy course would not necessarily be indicated at its full value in the results of the Cooperative Test Service tests.

The tests given in 1942–43 did not provide as striking scores as the earlier ones. The 50-percentile score of the cadets in mechanics, heat and sound was 43, as compared with the engineering school figure of 41 and the male college value of 38. In light and electricity the cadets scored 30 against 28 for the engineering schools and 26 for male college students. The falling off is probably attributable to several factors arising out of the war. The introduction of flying training for cadets during this academic year was probably a disturbing factor academically; the course was slightly shortened; a larger number of new instructors than usual had to be assimilated; and

in time of war the elimination of cadets for academic deficiency is probably not carried out with the same ruthlessness as in time of peace, with some resultant slackening of the pace all along the line. Of the class that took the 1939–40 tests, 17 percent had been discharged for scholastic reasons by the end of their first year, whereas only 12 percent of the class taking the 1942–43 test had been dropped the previous year.

The final criterion of the effectiveness of the methods used at West Point is a more subjective one, and is based largely on my own experience. For the past year and a half I have in turn acted as instructor, assistant professor and professor under the system, and have taught sections all the way from the first to the last, as well as having supervised all the instruction.** It is my considered opinion that the West Point department does an outstanding job of carrying out its specialized mission. I believe it does more for the average student than any system I know of. The outstanding student is probably no better off at the Military Academy than at any other good institution of collegiate status; in fact, the rigidity of the system may occasionally handicap a gifted but highly individualistic man. The run-of-the-mine student, on the other hand, and in particular the man in the lower half of the class, gets far more attention than is usual at other places, and I believe the results show it.

COMMENTS AND CONCLUSIONS

By the criteria used to judge the physics faculty of a university the West Point department would not appear to be very strong. These criteria usually include advanced degrees, published research, authorship of textbooks, numbers of graduate students, and the like. It should be obvious that these criteria are not valid for the Military Academy because of its peculiar function. The true measure of the department's strength is the degree to which it accomplishes what it sets out to do. If my analysis of its success in instruction is correct, one can only conclude that the department has been most efficiently administered and that its personnel does an excellent job. When one knows the situation at first hand there is no reason to expect anything else than excellence. It is true that the instructors are not trained for the academic profession and do not have the academic viewpoint. On the other hand, they are men selected for recognized ability, who have had a sound engineering education. Most of them have had further training in the service schools or at civilian engineering schools. All have had practical experience outside cloistered academic walls, and in their late twenties and early thirties they are vigorous and enthusiastic. Because a large percentage of an army officer's time is devoted to the training of troops, the Army is acutely conscious of pedagogic methods, and its officers are familiar with and have had practice in using most of the tested teaching aids. The fact that the instructors share a common office and are expected to spend their working days in it affords an excellent opportunity for the exchange of ideas, with the result that there is much informal education of the newer instructors by the more experienced. The morale of the department is maintained at an unusually high level. I have never been a member of a group of comparable size that had a finer spirit of cooperation toward a common goal, or such contagious and continued enthusiasm for the job at hand.

I have been particularly impressed with the way in which competent instructors are created out of men with no previous special training except a general engineering course at the Military Academy. Given an individual of some native intelligence and with an engineering degree, it is remarkable what progress can be made in a summer toward making him a creditable teacher of general physics. I believe that the same methods can be (and no doubt have been) applied at colleges and universities confronted simultaneously with large numbers of Army and Navy trainees and serious manpower shortages in their science and mathematics departments. If the course is carefully planned in detail and the instructor training program is carried out with vigor and cooperation by all concerned, surprisingly good results can be attained.

** The author could have added that in forming his judgments he has the background of having taken the bachelor's degree at a men's college of liberal arts, at West Point and at one of the country's leading engineering schools, of having done graduate work in this country and in Germany, and of having had 15 years' teaching experience in a men's liberal arts college.—EDITOR.

A criticism often aimed at the Military Academy as an educational institution is that it suffers from inbreeding. It is true that in normal times the faculty is almost completely inbred, in that almost all its members are West Point graduates. This statement is somewhat deceptive, and needs some analysis. During the past score of years about half of the Academy graduates had attended college before admission, and of this group nearly half had had two or more years of college. Furthermore, many of the graduates in the Corps of Engineers, the Signal Corps, the Ordnance Department and some other branches take postgraduate work, often leading to advanced degrees, in universities and technical schools. As a result of the way in which instructors are selected, it usually happens that a large percentage of those present at any one time have had as much residence at college or university as they had at West Point as cadets.

Despite the foregoing ameliorating circumstance, however, I believe there is some validity to the complaint of inbreeding. The war has brought a numerically significant influx of college professors and instructors onto the academic staff (by temporary appointment as officers in the Army of the United States). The reaction of these men to the system has been quite generally favorable. I find many of them deeply impressed with the work of the cadets. On the other hand, I believe they in turn have had an important influence upon the system here. More than one Regular Army officer in the science departments has told me that he sincerely felt that the level of instruction had been improved by the addition of college teachers to the staff. There are certain technical difficulties in the way of continuing this practice after the war. If these could be overcome I believe it would be of mutual advantage if each department at West Point could arrange to have one or more professional college teachers present at all times as, shall we say, "visiting" instructors. The actual procedure would have to be worked out in detail, but one method would be for cooperating colleges to loan faculty members to the Academy on a leave-of-absence basis. To satisfy the military requirements such individuals could be given reserve commissions and ordered to active duty for the necessary periods.

The division of responsibility among the science departments at West Point has struck me as somewhat unorthodox. In particular, the union of chemistry and electricity in a single department is a strange one to a physicist. It is easy to understand historically, as the two were wedded in 1856, when the voltaic cell was the common source of electric current. In the twentieth century a divorce would logically be in order, with physics as the corespondent. As a practical administrative matter, however, the unusual combination works out quite satisfactorily. Of course, one could make out a good case for a second year of physics, in which some material now taught as electricity and some taught as mechanics would be transferred to the physics department. The trend in good engineering schools should be toward increasing the amount of basic physics required of the student before he specializes in some particular branch of engineering. It is quite possible that a better integration of the West Point curriculum would result from the addition of a second year of physics, thereby relieving the electricity and mechanics departments of some teaching of basic theory, and permitting them to spend more time on engineering applications, which in the current military establishment are multitudinous. When one considers, however, that the West Point departmental organization is largely based on administrative convenience, the practical value of such a change is open to question. Instead of being head of a department in the university sense, with many different courses operating under him, the West Point professor is actually the head of what in a university would be a single course, or at most two courses. What the names of the courses are makes little difference, provided its head is professionally competent in his particular subject, which is now the case.

In my opinion the outstanding feature of the instruction in physics at West Point is the fortunate combination of physical plant and numerically adequate teaching staff which permits a daily lecture-demonstration method of presentation to be combined with daily blackboard problem work in very small groups. It seems to me an ideal system, and one which would be adopted widely if circumstances permitted. In most places lack of duplicate equipment requires

lecture-demonstrations to be given only to large groups in a big lecture hall. From my own experience both as listener and lecturer, and from the comments of many students over a period of many years, I am convinced that the value of such instruction is in inverse ratio to the size of the group. On the other hand, I am sure that there is great value in having actual demonstration apparatus in the classroom where it can be seen and handled by the students. The situation at West Point is as near that of Mark Hopkins, with plenty of apparatus, on one end of the log and the student on the other, as any practical working method for a large beginning course could be. The instructor can be reasonably sure that he gets his demonstrations across to 14 or 15 cadets, and he can give personal attention to each man in the problem work at the blackboards. At the same time the student knows that deficiency in his daily preparation is bound to be detected, so he studies regularly instead of spasmodically. The whole system is of course predicated on the belief that *all* the students should be educated. Naturally it will not appeal to a school of thought not infrequently encountered which holds that it is a waste of time to expend pedagogic effort on any except superior students.

SUMMARY

Instruction in physics as such at West Point is limited to a single basic pre-engineering course in general physics, required of all sophomores. The department is excellently equipped for this purpose in every respect, including classroom and laboratory facilities, apparatus and teaching staff. Under the able administration of Colonel G. A. Counts, Professor of Physics, a system of instruction has been developed which produces results that compare favorably with those of collegiate institutions of the very first rank. The core of the West Point method is the combination of daily lecture-demonstrations with individual blackboard work in the solution of problems for small groups—not more than 15 students per section. It is the opinion of the writer that any physics teacher concerned with the problem of conducting a large elementary physics course at the college level would find a visit to the Military Academy physics department both interesting and professionally profitable.

The Part That Physics Plays in the Navy

FRED KINGSLEY ELDER*
United States Naval Academy, Annapolis, Maryland

MANY of the physics teachers who are participating in the Navy V-12 program have expressed uncertainty as to the aspects of physics that should be stressed. This has been a problem at the U. S. Naval Academy also, and in the last three years considerable effort has been made to solve it. Although some of the conclusions which we have reached may not apply to the V-12 program, those that seem applicable are presented.

It must be recognized at the outset that many of the duties of a naval officer parallel closely those of civilian engineers in many fields. And, since these do cover many fields, it is apparent that the only logical and effective approach is through a mastery of the basic principles of physics. Consequently, methods of presentation that have been found effectual in the past may still be applied with confidence in the future.

The topics which should be emphasized in physics are classified under the following headings:

Seamanship	Fire control
Navigation	Torpedoes
Ordnance and gunnery	Marine engineering

Electrical engineering.

Seamanship has to do with ship handling and maneuvering, as well as with the handling of gear and weights; it is concerned with the effects of wind, currents, tides and weather. *Fire control* is a technical term covering the direction, accurate control and rapid firing of guns and torpedoes. *Marine engineering* includes all that is ordinarily studied in colleges as mechanical engineering,

* Commander U.S.N. (Ret.) and Head of the Physics Committee, U. S. Naval Academy. The opinions expressed in this article are those of the author and are not to be construed as necessarily those of the Navy Department or of the naval service at large.

with the addition of damage control—a technical term dealing with stability of floating bodies, as well as the quenching of fires and the minimizing of other damage.

The classified list that follows is not exhaustive, but merely suggestive. It does, however, cover in general those topics of physics that are essential in the education of a naval officer. Many of the topics appear under only one heading, but are, nevertheless, applicable to other headings. Such things are left to the initiative, imagination and intelligence of the physics teacher.

Topics and their applications

Seamanship

Force. Handling of heavy weights on board ship. Ships in tow. Rudder action. Winds and currents.

Mechanical advantage. Multiplies the usefulness of man power.

Pulleys. Make possible hoisting out and in of boats by man power when electric or steam power fails.

Buoyancy. Flotation and loading of boats as well as ships.

Bernouilli theorem. Handling of ships and boats alongside moving vessels.

Statics. Thrusts and loading on ships' cranes.

Navigation

Vectors. Used in piloting, on the maneuvering board and in aerial navigation.

Gyroscope. Used as the directive force in the gyrocompass.

Sextant. Illustrates the principle of doubling the angle of reflection of a ray of light on a rotated mirror.

Terrestrial magnetism. Magnetic compass. Variation, deviation and dip used in compensation of the compass.

Lenses and prisms. Used in nautical binoculars, spyglasses and range finders.

Polarization of light. Reduction of glare.

Bernouilli theorem. Pitot tubes in speed indicator.

Sound. Sonic depth finder.

Ordnance and Gunnery

Motion with constant acceleration. Used in gun and turret training and elevating equipment.

Trajectories and freely falling bodies. Used in computing range, angle of elevation, angle of fall and maximum ordinate of shells in flight (exterior ballistics). Used also in determining time and place for bomb release.

Gas laws. Used in the computations of interior ballistics (what takes place within the gun when fired).

Sound. Sound beaming to determine the presence of a ship or submarine.

Fire Control

Light. Polarization, reflection and refraction.

Lenses. Used in periscopes, spotting binoculars, range finders and gun telescopes.

Mirrors and prisms. Used in range finders, check telescopes and binoculars.

Thin films. Used to minimize reflection of light from lenses and other glass surfaces.

Telescopes. Used on guns and fire control directors.

Periscopes. Used on submarines, turrets and armored fire control stations.

Gyroscope. Stabilized gun sight.

Torpedoes

Gyroscope. Controls path of torpedo in azimuth.

Hydrostatics. Controls path of torpedo in depth.

Buoyancy. Controls size of explosive charge and amount of fuel carried.

Turbine. Motive power unit.

Levers. Control motions of parts of torpedo and rudder operating gear.

Center of gravity. Controls attitude of torpedo.

Gas laws. Concerned with transfer of energy.

Marine Engineering

Fundamental units. English units are used largely.

Force. Prime movers and auxiliary machinery.

Energy. Heating value of fuels.

Thermodynamics. Heat analysis.

Elasticity. Strength of materials.

Moments of inertia. Rotors, shafting, rolling and pitching of ship.

Simple harmonic motion. Elimination of vibration.

Metacentric height. Damage control.

Wave motion. Rolling and pitching of ship.

Statics. Analysis of structures.

Vectors. Analysis of stresses.

Motion with constant acceleration. Inertia of moving bodies.

Rotational motion. Operation of machines.

Density and specific gravity. Analysis of fuels.

Change of state. Ice and steam plants.

Calorimetry. Steam plant.

Conduction, convection and radiation. Analysis of heat transfer.

Carnot cycle. Analysis of heat utilization.

Electrical Engineering

Electric field, potential, resistance and current. Basic concepts of electricity

Ohm's law. Calculation of loads on conductors. Heat losses in electric machinery.

Kirchhoff's laws. Circuit analysis.

Metric units. Groundwork for system of electric units.

Cathode-ray tube. Used in oscillograph or oscilloscope.

Vacuum tubes. Used in communications, radio and underwater sound gear.

Motors. Prime movers, deck winches and capstan.

Generators. Lighting, firing circuits and underwater sound.

Circuits. Radio, lighting, interior communication, gun firing, sight lighting, telegraph systems and visual systems.

Magnetism. Degaussing.

The study of physics demands exacting and accurate reading. Development of the habit of such reading is essential in the naval officer. Problem solving, traditionally a part of the physics course, is equally essential. From these two abilities the student is exercised in reaching accurate and sound conclusions quickly—a priceless naval quality.

Roland Roy Tileston, Nominee for the 1943 Oersted Award

A. G. WORTHING
University of Pittsburgh, Pittsburgh, Pennsylvania

IT is appropriate at this time that we state the basis on which Oersted awards are made. Accordingly, we refer to the original report of December 2, 1935, by the adoption of which the awards were established. Referring to the committees which should be concerned with the selections of nominees, it provided that "the duties of this committee shall be the recognition of distinguished teaching and outstanding contributions to the teaching of the science of physics."

In the search for an Oersted Medalist, we accordingly do not give consideration to any research activity unless that activity somehow concerns the teaching of physics, we do not give consideration to articles or books published unless by their publication some improvement in physics teaching seems to have resulted, we do not give attention to activities unless the teaching of physics has been bettered thereby. The selecting of a best candidate under these limitations is not easy.

We have, of course, a great help in the AMERICAN JOURNAL OF PHYSICS, but it emphasizes only the publication phase, a phase which, though very important, should not predominate in the selection of a medalist. Except for this journal we have had until recently but little that was objective. Thanks now to the search for the undergraduate origins of physicists that was conducted by my colleague, O. H. BLACKWOOD,[1] we have an added test for selection. We can now ask, regarding our candidate, whether or not he has been productive in stimulating young men and women with a desire to become physicists and we can expect a reasonably definite answer.

In the making of the past seven Oersted awards, choices have largely, though not entirely, centered on men who have made themselves known by other activities, as well as by teaching. This is but natural under the circumstances and, of course, there is no objection to a candidate being well known, or even famous, for other activities.

This year the committee in charge of the selection early decided that it was desirable to choose, as a candidate for the medal, one who would be representative of that group of physics teachers who, because they are connected with small institutions of learning find it difficult to make themselves widely known. PROFESSOR BLACKWOOD's summary of origins revealed many such teachers with enviable records. It was largely the source of information for the choice that was made. Leading the list of physics professors who could be said to be almost entirely responsible for the graduate careers in physics which their students had chosen, but only slightly ahead of three or four competitors, was PROFESSOR TILESTON, of Pomona College, Claremont, California. He is the committee's candidate for the 1943 Oersted Medal.

ROLAND ROY TILESTON, born in Randolph, Massachusetts, April 28, 1886, was granted an A.B. degree by Dartmouth College in 1907 and an A.M. degree in 1911. He was an assistant in physics at Dartmouth from 1908 to 1911. He left Dartmouth because of a serious setback in health and went to Colorado where he served as a civil engineer in 1912–1913. He was made professor of physics at Colorado College in 1913

[1] Am. J. Phys. 11, 46 (1943).

and served in that capacity until 1925; in the meantime, he also served the City of Colorado Springs for five years as a consulting engineer. In 1925, on leaving Colorado College, he was awarded an honorary Sc.D. degree by that institution. Since then he has been in charge of physics at Pomona College in Claremont, California.

During World War I, PROFESSOR TILESTON was Director of the U. S. Army Radio School at Colorado Springs. During World War II, he has been successively: director, Civil Pilot Training for Civil Aeronautics Administration (primary and avanced programs) 1941–1942; personnel procurement officer, Naval Research Laboratory, 1942–1943; and academic director, Army Air Forces Premeteorology Program, Pomona College, 1943–1944.

PROFESSOR TILESTON was married, first in June 1915, to BETTY HAZEL GARDNER, who died in June 1941. Somewhat over a year ago he married MRS. EDGAR BASSET WASHBURN. There are three married daughters.

Ordinarily a serious sickness is viewed as a calamity. There is some doubt, however, about the sickness that caused TILESTON to leave Dartmouth in 1911. PROFESSOR GORDON FERRIE HULL in speaking of the occasion indicated that it had been the intention to retain him at Dartmouth. Had he been so retained, the opportunity to go forward independently, as he did at Colorado College and later at Pomona, might not have come until too late. Be that as it may, the opportunity for independent action came to him in the West and he took advantage of it.

PROFESSOR TILESTON has not been widely known. There is little or nothing in the way of research or other papers which he has published. His great claim to our attention lies in the large number of his students who have gone forward in physics to obtain advanced degrees. There are 30 who have obtained M.S. degrees and 24 others who have continued for Ph.D. degrees; and, judging from the replies which have come from several of these that the speaker has selected through the acquaintanceships of a colleague and of himself, his reputation among them is of the very best.

The letters just referred to have been in surprising agreement regarding several important characteristics of the man and teacher. They indicate, on the one hand, a high respect and appreciation of his alma mater and of PROFESSOR HULL, to whom he once wrote, "One of the strongest influences in my life has been that of my chief at Dartmouth." On the other hand, they uniformly indicate an equally high appreciation of the influence that PROFESSOR TILESTON has had on their own lives. KENNETH OGLE says: "To Professor Tileston I owe a great debt. He was one of those outstanding personalities that in men's lives not only mark turning points, but also indicate the paths. It was he who started me on a career of physics." J. BARTON HOAG says: "There have been two people in my life who have wielded great influence. One was my mother and the other was R. R. Tileston." J. G. WINANS says: "I might add that my own personal appreciation of Dr. Tileston is so great that my wife and I have named our son (now two years old) Theodore Roland in honor of Dr. Roland R. Tileston." Letters from Miss Adelaide Easley and Curtis Haupt show between their lines appreciations that are equally great.

Regarding teaching procedures, these letters are equally in agreement. MISS EASLEY says:

> He presented such a vivid picture of Bohr's atom, Bragg's crystal structure models, Einstein's theory of relativity and many other subjects to us undergraduates that often we would continue the discussion for an hour or two after he had left us. Later, in graduate school, those subjects seemed like old friends, and still do, because he painted them so clearly. He taught us the technique of starting an unfamiliar problem, of using the library to get our background, and then of setting up our experiment. As a result, new problems and new apparatus have been a challenge and a game instead of a threat and a burden. He taught us to keep our data in such form that it would always be clear and usable at any time. As an undergraduate, I sometimes resented his insistence on keeping "good" notebooks. Now I feel that the technique of keeping data was one of the most valuable things he taught us, for the habits formed then have resulted in my being able to go back to my Nela notebooks of 10 and 15 years ago and use the data taken then almost as readily as the data taken yesterday.

According to MR. OGLE:

> In the classroom he was a demanding teacher. He insisted on high grade work and close application to details. With this approach he forced his students to

think, often, it must be admitted, because "of the fear of God in their hearts," rather than any basic interest in the material.

According to MR. HOAG:

> Tileston was a Quaker by faith and very strict with the men around him. In fact I saw him put a man out of the physics department primarily for getting mad over a certain experiment and saying "Damn it." He was a strict disciplinarian, had a strong willpower but did not demand of others what he did not demand of himself; but, believe you me, that was plenty.

MR. WINANS states:

> Professor Tileston was my first physics teacher at Colorado College in 1919, and the one who influenced me to major in physics. In all of my subsequent experience, I have not found anyone who could teach as well as Professor Tileston. He was enthusiastically alive with his subject and he inspired enthusiasm in his students. His thinking was clear-cut and his presentation so well made that subjects which with any other teacher would have been complex and baffling became well-ordered, logical and natural. Professor Tileston put his whole self into his teaching. He expected a lot from the students, and they were inspired to give a lot.

As a lecturer to his classes and to the public he seems to be outstanding. Quoting MR. WINANS further:

> Every year Professor Tileston gave an "Electron Lecture" which was open to the public. The lecture was given in the evening and was so popular that it usually had to be repeated several times. In this lecture the story of electrons was told with many demonstrations which had been carefully prepared and timed. In these lectures Professor Tileston showed how ably he could hold the interest of his audience through excellent description and performance of demonstration experiments.

After leaving Colorado College, PROFESSOR TILESTON established a survey course in physics at Pomona College. Of this MR. HAUPT says:

> He was convinced that much could be done to popularize physics for the nonmajoring student—to make it more attractive so that many more students would elect the course for its cultural value. Thus he came to pioneer a unique survey course which has been so successful that each year many students who wished to take it have been turned away, the limit of enrolment being the capacity of the lecture room, which is about 120. No other course in any department in the college can demonstrate a similar drawing power. The success of the course stems first from the character and number of demonstrations used. Almost every principle is illustrated by means of a demonstration. Sound motion pictures are also extensively used. Blackboards are not employed, the necessary material being projected by lantern slides instead. Professor Tileston devotes himself exclusively to the lecturing, and all demonstrations are handled by student assistants. The demonstrations are carefully rehearsed in advance so that the entire program runs smoothly and with perfect timing. In making the demonstrations appealing, emphasis has been put on the use of color, motion and large size.

PROFESSOR TILESTON was uniformally declared to have made sure that his majors had positions to fill on graduation. Most of them seemed, as a matter of course, to have gone to another institution for advanced work, a very large percent to his alma mater, Dartmouth. PROFESSOR HULL greatly appreciated this source for graduate assistants. He states, however, that he was sometimes disappointed. But from the large number who came to him what else could be expected. It is too much to ask that all of one's product shall be top notch.

As a go-getter for his department in obtaining funds and equipment, PROFESSOR TILESTON seems to have been very successful. One former student says:

> Under his direction, the physics department at Colorado College grew from almost a nonentity to a bang-up liberal arts course. Equipment, room space, lecture demonstrations, staff—all were enlarged and improved. His classes were alive with new discoveries, new applications and new apparatus.

Professor Hull speaks similarly of his activities at Pomona and concludes with the words, "presently his department stood out high above the others."

Mr. President, in the name of the Committee of the American Association of Physics Teachers appointed to nominate a candidate for the Oersted Award of 1943, I am pleased to present the name of ROLAND ROY TILESTON, of Pomona College, an outstanding physics teacher, as our nominee for that award.

Roland Roy Tileston

Recipient of the 1943 Oersted Medal for Notable Contributions to the Teaching of Physics

The American Association of Physics Teachers has made to Professor Roland Roy Tileston, of Pomona College, the eighth of its annual awards for notable contributions to the teaching of physics. The addresses of recommendation and of presentation were made by Professor A. G. Worthing, a member of the Committee on Awards, and Professor Lloyd W. Taylor, President of the Association, on January 15, 1944, during the thirteenth annual meeting of the Association. Since Professor Tileston was unable to be present because of pressure of war work and difficulties of travel, he was represented at the ceremony by his former teacher, Professor Gordon Ferrie Hull, of Dartmouth College. A communication from Professor Tileston, which was delayed in the mails and received too late to be read during the ceremony, is included in the present published account.

Presentation of Award by President Lloyd W. Taylor

Back of every signal accomplishment, whether in the sciences or in the other disciplines, will be found men possessing the spark of inspiration and the fire of zeal to do. Service will be rendered to humanity in just the measure that men continue to be so inspired and motivated.

One of the basic fields in which men must continue to be soundly trained, for war and peace alike, is physics, the most fundamental of all the sciences. Some of the most faithful servants of society devote their lives, unheralded, to the discovery and development of productive scholars possessing the peculiar aptitudes involved in this field. This Association was founded to support the work of just such men and women. Notably appropriate, therefore, are the good offices of the anonymous donor who for a number of years has made it possible for the Association to select and award public recognition to an outstanding representative of the small army of faithful producers of producers of physics.

It is a privilege to present, in the name of the American Association of Physics Teachers, the Oersted Medal for 1943 to Professor Roland R. Tileston, of Pomona College.

Remarks by Professor Gordon Ferrie Hull

IT is with a feeling of great satisfaction, of pride—I might almost say of parental pride—that I, representing the Department of Physics in Dartmouth, act as proxy in receiving this medal for PROFESSOR TILESTON. I was to have read PROFESSOR TILESTON'S acceptance address, but the manuscript has not arrived. It would be presumptuous on my part to attempt to anticipate his response, but I may be permitted to supplement PROFESSOR WORTHING'S presentation.

PROFESSOR TILESTON'S first year after graduation was not to his liking. He returned to Hanover in the summer of 1908 discouraged and depressed. He had not been making progress during the year. He wanted to continue the study of physics. Could we give him a graduate student assistantship? Our department so voted. His next three years with us were years of happiness and growth. In the realm of physics new vistas had recently been opened: x-rays, marvelous, mysterious as to their nature; the electron, the smallest known particle which seemed to have assumed command of the universe; radioactivity, responsible on the one hand for the breaking up of some atoms, on the other hand for building up our ideas of atomic structure; quantum ideas, pushing in to dispossess those of continuity; and in a very different field, "wireless," miraculously tapping out signals across the Atlantic. All of these fields were alluring; they offered unlimited growth. Moreover, the opportunities for wholesome recreation in Hanover were excellent. In winter, on the snow-covered hills, there were "experiments on an inclined plane"; in all seasons, tramps through the scenic hills. The three years 1908–1911 were for TILESTON years of growth and happiness.

Then suddenly a cloud arose, a cloud on his lungs. Tuberculosis made its appearance. He left suddenly for Colorado, lived in the open air, fought hopefully and with determination for his health. This he regained. He secured a position in Colorado College. A new lease on life had been given him. He entered into his work with great energy and enthusiasm.

Presently, letters came to us. Would we appoint one, two of his men as graduate assistants? He wanted his men to continue at once their study, not to lose a year as he did. Year after year these letters came. We invariably found a place for at least one of his men. Dartmouth College and Hanover had a strong appeal, partly on account of contrast, for men in Colorado and California. Consequently, many of TILESTON'S men have been graduate assistants in Dartmouth.

Here, then, is one characteristic in which Tileston has excelled. He has taken care of his men. He has secured for them, before their graduation, positions in which after graduation they could continue their study. His energy, zeal and enthusiasm have borne good and abundant fruit. It is for such excellent performance that we today honor Professor Tileston.

Communication from Professor Tileston

Aside from several periods of engineering, my life work has been concerned with the details of teaching and with the lives of the men taught. There has been constant inspiration from contact with the minds of these young men. Also, there has been a stimulation in being a link in the chain of transmission of a type of knowledge and human endeavor which carries the elements of drama based on fact.

The Oersted Medal must then be accepted by me for the men whom I have been so fortunate in having as students and who later accomplished certain worth-while tasks in the field of physical science. In the names, then, of these men and others who I hope will follow, I gratefully accept this medal as an indication of their achievement and as a challenge to me for my future work in the teaching of physics.

Comments on the Teaching of College Physics by Nonphysicists *

W. Weniger
Oregon State College, Corvallis, Oregon

THE present shortage of physicists, coming at a time when enrolment is exceptionally heavy owing to the Army and Navy programs, has led to the practice of borrowing instructors from other departments to help out in the emergency. Such instructors bring with them a wealth of teaching experience in other fields, and points of view differing from those of professional physicists. This offers a rare opportunity for obtaining constructive criticism of the first course in college physics as to both course content and the customary teaching technics. Accordingly, the Oregon section of the American Association of Physics Teachers arranged an afternoon program of five papers prepared by a high school teacher, a botanist, a chemist, an agricultural engineer and an educationist. Those taking part in the ensuing discussion represented, in addition to the aforementioned departments, English, engineering, pharmacy and zoology. All of those present had experience in teaching from one to three soldier-terms. There follows a brief abstract of each paper, and a summary based on the papers and the discussion. The institutions represented were the University of Oregon, Willamette University and Oregon State College.

C. L. Church, for 15 years a high school teacher of political science, mathematics and physics at Myrtle Point, Oregon, and now instructor at Oregon State College

First, I wish to remark that we "new" instructors have a teaching advantage: we have to prepare carefully and thoroughly. My views can be expressed very quickly by calling attention to certain contrasts between my past experiences and those at the college: the lack of problems of discipline; the absence of those who do not want to learn anything and of those who cannot, but who hold back the class as a whole; the high general average of willingness to learn; the advantage of more and better apparatus both for laboratory and demonstration. It is likely that many of these contrasts are especially marked because the Army Specialized Training Program is being taken by men who are neither typical soldiers nor typical college students. The same difficulties exist here as in high school: lack of mathematical preparation, particularly in arithmetic; inexperience in reasoning; inability to employ symbols. There is insufficient time to give the necessary drill that enables the students to assimilate the wealth of new concepts. If we see how hard even good students try to avoid doing things the easy way, we gain patience with the milling around of government officials in trying to solve their problems.

W. M. Atwood, Professor of Botany, Oregon State College

The large problems of teaching are not unique to physics. Physics has the advantage of referring to many well-known or at least widely distributed practical applications. In all sciences, precedents and professional demands crowd too much material into the first course; this is particularly noticeable in physics. New points of view are only gradually apprehended by students, and new information cannot be assimilated faster than at a certain rate; drill is necessary to make it stick. The approach to all the sciences is perhaps unnecessarily difficult owing to its specialized vocabulary, the use of logic, and abstract reasoning; so it becomes the task of the instructor to clarify and simplify and drill.

The research attitude is essential to the best teaching, and outstanding researchers should not be sacrificed to teaching. Conversely, no research ever can justify poor teaching effort. Achievements are limited chiefly by the horizons of the staff members; Upsala, a small Swedish university, on account of Linnaeus attracted the best of the scientific world. It behooves us, who are not in our own special fields, to study critically the teaching technics of others. A good instructor achieves "resonance" with his students by enthusiasm, simplicity, dramatization and friendliness.

The function of the lecture is not entirely factual; it should also promote interest. The laboratory not only provides illustrations of principles and measurements of a few quantities, but also opportunities for teacher and student cooperation: the chairs may be left in place, waste paper put in the baskets instead of being left on the tables, and apparatus left as at the beginning of the period. All of this simplifies the necessary check of apparatus before the next section appears. The recitation fixes new concepts by repeated approach to them, using the all-important discussion supplemented by problems. More problems are desirable even if the speed of covering the field must be reduced; many simple problems and some longer ones are essential; tricky problems have little value in a beginners' course. The unforgivable sin is to permit the solution of problems in numerics only, with consequent guessing at units.

* Published with the approval of the Monographs Publication Committee, Oregon State College. Research paper No. 79, School of Science, Department of Physics.

D. S. Dedrick, Assistant Professor of Chemistry, University of Oregon

Chemistry has outgrown its mother science, physics, as to the number of degrees granted and the number of people using the subject matter. Much of what I have to say will be said by contrasting physics and chemistry. By this time I have had two years' experience in teaching "Essentials of Physics" (2 lectures, 1 laboratory, for 1 year), as well as courses for pre-meteorology and pre-engineering.

The lower division student in general grasps descriptive matter with little effort, but finds the quantitative relations difficult. This is due chiefly to poor high school preparation in algebra and geometry. The student has not learned to transfer from word statements to formulas and vice versa. In first-year chemistry, the number of essentially different quantitative concepts amounts to perhaps a dozen. In first-year physics, Hausmann and Slack give 270 numbered relations and Perkins approximately the same number. Students attempt to memorize these. The subject matter also comes so rapidly that they attempt to memorize that as well. This situation may be remedied by drastically reducing the number of formulas, which can be done by working problems entirely by means of fundamental concepts and definitions instead of by special derived relations. Needless to say, units should be emphasized more than they generally are. To reduce still further the amount of material, it may be wise to leave to the engineering course detailed references to industrial processes and applications and materials and to operate the general physics course from the point of view of "Natural Philosophy." Another suggestion is that the present first-year course be expanded to two years. The amount of material presented would then be comparable to that in the corresponding parts of the well-established sequence in chemistry: general, analytical, organic and physical.

Comparing student reactions to the present first-year courses in physics and in chemistry, there is little difficulty in keeping up interest in chemistry all year, but in physics there is a cowed and overwhelmed attitude on the part of the students at the end of a few weeks. There is too fast a sequence of concepts and a consequent lack of retention of material. Upper division students employed to read daily assignments in chemistry as a rule need no key, but in physics a complete key is almost always requested, as these men are not sure of themselves.

Quiz or recitation periods are necessary to iron out difficulties. The more experienced the instructor the more valuable is the time spent in recitation. It is generally conceded that a person retains more of what he sees and does than of what he hears; but in the laboratory, the experiments can be so long, and in both laboratory and lecture, the apparatus can be so complicated and the manipulations so complex as to make the student lose sight of the central idea. The lecture should not be primarily a show. The lecture should precede the laboratory, and a pre-laboratory discussion is valuable before using the apparatus.

I wish to emphasize that this is not an appeal for a "pipe" course, but a suggested method of making first-year physics a more valuable part of any curriculum. My reaction is that a student who has completed a course in general physics does not have the grasp of the material which his time and the importance of the subject warrant.

W. J. Gilmore, Professor of Agricultural Engineering, Oregon State College

By way of personal background, I wish to say that I was brought up on a farm, and between Manitoba and Oregon State College have for more than a third of a century taught engineering in agriculture. My contacts have been with farmers and with firms supplying farm equipment. All of this has naturally given me a deep interest in physics. I am convinced that the applications of physics to agriculture are more numerous than those of chemistry, and that physics should occupy a prominent place in the agricultural curriculum. Some of the points of contact are soil physics, farm water supply and irrigation, farm machinery and power, farm electrification, refrigeration and cooling, drying and dehydration of fruits and vegetables.

I find that first-year physics as now taught is very difficult for the average student. Some parts can be simplified and others made more interesting by means of problems as they occur in practice, with not all of the items conveniently presented, rather than problems that require merely the selection of a formula and substitution therein. It may be desirable to begin the year's work with two or three weeks of review of parts of algebra, geometry and some trigonometry, and with practice in arithmetic computation. The need is to cover less and do it more thoroughly. The remedy appears to be either expansion of the time allotted to the course or the introduction of different courses consisting of selected topics for different groups of students.

ASTP students should have an interest in engineering or physics and not be assigned to engineering, and therefore to physics, merely because of a high I.Q.

Elmo N. Stevenson, Professor of Science Education, Oregon State College

I agree with most of the things that have been said: the difficulty of the subject, the reasons therefor, and especially the statements regarding the enormous amount of factual material presented. Instead of proceeding with additional personal testimony along these lines, I wish to present briefly some evidence that may clarify some of the points raised.

The chief point made seems to be that there is a large amount of material presented and that it is not too well absorbed. Five diagnostic studies have been made on the teaching of science at secondary and college levels by Goss, Black, Bail, Rayler and Hurd, and Noll[1] and reveal:

(a) A low order of attainment in the fundamentals of physics.

(b) Little ability to apply principles even when known.

[1] V. H. Noll, *The teaching of science in elementary and secondary schools* (1939).

(c) Vagueness or mistakes in concepts.

(d) Weakness in understanding and using the vocabulary of physics.

(e) Difficulty most frequently in arithmetic.

The low order of attainment is verified by our own testing program. In zoology, the average attained on a certain examination was 75 percent; the same examination given a year later to the same students (as far as they were available) gave an average of 35 percent; another year later the average was 18 percent. In botany the corresponding averages were 75, 30 and 16 percent.

It appears that only 42 percent of a lecture is remembered the next day. Since the memory can be trained, it is up to us to do so.

The language of the sciences is abstract and frequently that of the formula. Its mastery requires time. In college biology, freshmen are unable to define or illustrate more than 1800 words on an average. Some physics textbooks introduce 72 new words and symbols in the first chapter.

Success in algebra seems to require an I.Q. of 110 or better. The ASTP students have 115 or better and yet one-fourth fail, chiefly because of mathematics.

In 1910, physics had a leading position in the high school curriculum. Now it is near the bottom, only Latin having a smaller enrolment. Whether high school physics is desirable as a prerequisite to college physics is not known; statistics differ widely. Our own seem to show that at the end of the first year there is no difference in the grades attained by those who have and those who have not had high school physics.

Henry Dual claims that the same understanding of fundamentals is obtained without as with student laboratory, and yet G. S. Hall states that, when attending, 0.1, 0.3, 0.5 and 0.7, respectively, of what you hear, see, say and do becomes a part of you. Hunter, of Claremont College, finds in a survey of 2200 secondary and college schools that methods in use in the sciences are, in order of frequency: lecture, discussion, text, demonstration by teacher, individual laboratory, work book, references, pupil demonstration, visual aids, individualized instruction, projects, field work. Note that the most effective methods are used least frequently.

There is sufficient disagreement between experimental indications and teaching practice to provide a good field of study jointly by specialists in physics and in education. The influence of the individual teacher is marked.

SUMMARY

There seems to be something wrong with the first year of college physics whether the course be for liberal arts students or for professional groups, such as engineers. Possibly the many textbooks that have appeared during the last decade are an indication of this fact, each author attempting a more teachable presentation. The fields covered by these textbooks do not differ markedly, but the group as a whole contains a wider spread of subject matter than do older books. There has been a tendency on the part of physicists to include most new discoveries in the first-year course. At the present time, according to our temporary teaching colleagues, the course is definitely overloaded. It seems that physicists talk about stressing fundamentals but do not provide the proper conditions to make this possible.

The remedy seems to be reduction of content or expansion to two years. Reduction of content may be by the omission of fields or details or applications. Possibly the more difficult fields may be dropped, or those of little application to everyday life, or those of less interest and importance to particular groups of students. Perhaps theories may be omitted from the first course. We hear the statement that "physics is physics," but the objectives of courses, and therefore their content, may well differ for groups whose interests and backgrounds differ, as do those of students in liberal arts, engineering, agriculture and home economics.

Physics apparently has an advantage over other sciences in the use of problems as a teaching aid. Whether the problems be very simple or more complex or "practical" seems to be largely a matter of the background of both pupils and instructor. Physics should not give up its mathematical presentation and become descriptive.

Lecture, laboratory and recitation are all needed in teaching the subject. No one present felt that the demonstration lectures and the laboratory are illustrations of learning by playing. All were agreed that the instructor can present, encourage, aid, explain and clarify the subject matter, but that the student himself must put forth a conscious effort to master it. Applying physics to every-day affairs seems to be more difficult than understanding the general presentation. Possibly those parts of mathematics that will be used later should be reviewed at the beginning of the course, or at appropriate points in the course. The relative importance of teaching methods and teaching aids may well be made the subject of cooperative study by physicists and educationists.

Dynamic Tests for the Laboratory

Louis R. Weber
Colorado State College of Agriculture and Mechanical Arts, Fort Collins, Colorado

WHILE it is customary for many instructors in general physics to give written lessons and tests that include questions on the laboratory work, the author has always felt that more direct and reliable methods of testing laboratory technics could be developed. This idea was given further encouragement a few years ago. At that time a class was studying the Wheatstone bridge. The students were asked to show by a diagram the connections needed to make a bridge out of four resistance boxes in a row with galvanometer, cell and two keys in a second row. Only one of the 25 students was able to connect up these units as a Wheatstone bridge network. More than half of them wanted to rearrange the units into the traditional diamond-shaped layout, for most of them two days before had drawn and solved the bridge circuit in the diamond form. It occurred to the author that most students really do not comprehend what is fundamentally involved in the circuit or what essential condition must always be fulfilled. With the influx of electronic circuits in the laboratory, it is not always possible to lay out apparatus so that the wires follow the schematic diagrams. The following tests help to emphasize the fundamentals without too much of the mechanics of manipulation getting in the way of the principles.

These tests can also serve to broaden the students' knowledge of instruments and materials. If all of his work has been with resistance boxes, No. 13 in the following list will acquaint him with another form. In addition to determining the specific gravity in No. 5, velocity of sound in No. 7 and the refractive index in No. 22, the student becomes acquainted with some of the properties of Lucite. The use of apparatus involving the same fundamental principles but differing somewhat in form from the equipment previously handled by the students is worth while.

For a class of 20 students, ten or more different sets should be provided, with enough duplications so that each student always has a set to himself. Thus, several telescope sets may be made available and may be designated as, say, 27(a), 27(b), ... This provides available equipment for the faster students when slower students may be at work on sets not duplicated. At each set is a card with a number and simple directions. This card never indicates how the student is to proceed. For instance, No. 3 merely states: "Find coefficient of kinetic friction between board and block."

The examination experiments are chosen to include only basic principles studied in the classroom and laboratory. Before the student is given No. 10 he has measured noise levels at different places on the campus, from the kitchen in the Student Union to a quiet bench on the campus; however, he has not used an oscillator as a source of sound with variable output. In No. 8, although he has not previously measured the frequency of a block of wood, he has determined the velocity of sound with a tuning fork of known frequency. Similar remarks apply to all the examination experiments.

The number of experiments that can be used depends of course on the length of time available for the purpose. The author generally sets up 10 different experiments, or 20 counting duplicates, for a 2-hr laboratory period. With 20 students this has worked out satisfactorily.

The student goes to some particular experiment, and performs the assignment. On the examination paper, he writes his solution in a brief but adequate form, giving it a number corresponding to the number on the card attached to each experiment. The instructor moves around the laboratory making notes on the students' technic or checking results as in No. 9. He also can keep the students informed as to which experiments are free so that no time will be lost. If a student has obtained his measurements so that final calculation can be finished away from the experiment, it is suggested that he move to another station so that other students will not be held up.

The examination is graded on the basis of what the student has put down on the examination paper as well as on his technic as noted by the

instructor during the examination period. Because of the nature of the experiments—all of them being standard with recognized measuring technics—we believe that the students, to a large degree, can be graded objectively.

With the present method of conducting general physics laboratories where ten pairs of students are working with the help of laboratory manuals, it is not always evident what the individual abilities of a student may be. It is true that questions to be answered at the end of the experimental report give the instructor some insight into the students' grasp of the fundamentals involved in the experiment. However, if we assume that part of the laboratory objective is correct use of physical apparatus, then it seems obvious that this phase of the work can be tested only by actual manipulation. Anyone who has conducted a physical laboratory has had students who ordinarily would be rated as "A" or "B" on the basis of their recitations, written tests, and so forth, and yet in the laboratory these students seem to be completely bewildered if an open circuit develops in a slide-wire Wheatstone bridge. Another student who is barely making a "C" in his recitations and tests seems to be almost pleased when such unexpected situations develop.

The dynamic tests described in this paper help to give a truer rating to the student. If used properly, we find, they enable more "A" students in physics to get themselves out of difficulties arising from apparatus breakdowns or lack of equipment. The student who can measure the curvature of a lens with a spherometer may or may not understand what he is doing, but if he can perform test experiment No. 4 *without the spherometer* we can be practically sure that he does understand what the function and essentials of the instrument are, since *he applies them in another manner*. Some students, knowing that such a test is to be given, frequently spend extra time in the laboratory working with the equipment. Why an electric network made of actual resistors lying on a table should be more confusing to a student than the same network drawn schematically on paper could perhaps be attributed mostly to familarity *versus* unfamiliarity. These tests help to make the unfamiliar more familiar. As a result, some of the best students as reckoned by common standards will not do so well on these tests. Test No. 19 has been missed by many electrical engineering students while some of our so-called "C" students have passed it well.

The tests have not been given over a long enough period to warrant a complete statistical analysis, but the results are in general agreement with those of other tests with the exceptions previously noted. The final effect on all the students is good. They like the novelty of the test; and they feel that it is tremendously more worth while and will spend a much longer time in attempting to understand a particular experiment than if the same arrangement were outlined on paper.

The following list describes some of the dynamic tests that the author has used in his laboratory. Each item suggests necessary equipment and includes other comments that might prove useful.

1. *Vernier caliper*. Vernier caliper; meter stick; piece of wire. Measure the diameter of the wire to two significant figures. Some students will try to make this measurement with the meter stick.

2. *Forces*. String stretched between two points, with a known mass hanging at the midpoint; plumb line; protractor. Determine the tensile force in the string.

3. *Friction*. Board of medium length; block; ruler. Determine the coefficient of static friction. The more intelligent students will soon recall that this coeffieient can be found simply by measuring the tangent of the angle of repose with a ruler; others will not believe there is sufficient apparatus.

4. *Radius of curvature of lens*. Large plano-convex condenser lens; meter stick.

5. *Specific gravity*. Block of Lucite; beaker of water; spring balance.

6. *Atmospheric pressure*. Simple Boyle's law apparatus. Determine the atmospheric pressure. The student is expected to do this by taking two readings on the apparatus.

7. *Velocity of sound*. Lucite rod; Kundt tube. Determine the velocity of sound in the plastic rod.

8. *Frequency of block of wood*. Block of wood about 30 cm long supported about 6 cm from each end; brass tube; piston and mallet.

9. *Reverberation period*. Medium-sized room of simple design and furnishings near the laboratory; meter, two meter sticks; table of absorption coefficients. Determine the period of reverberation of the room when filled to two-thirds capacity.

10. *Noise levels*. Audio oscillator with gain control and loudspeaker; dollar watch; meter stick; key. Obtain the decibel difference corresponding to two different positions on the control. The student is expected to consider the

watch as a point source and to move it away from the ear until the ticking is just masked by the sound from the loud speaker; the power ratio P_1/P_2 in the relationship Decibel difference $= 10 \log P_1/P_2$ is set equal to the ratio of the square of the respective distances of the watch from the ear.

11. *Wheatstone bridge.* Four resistance boxes placed side by side in a row with a dry cell, galvanometer and key in front of them. Without moving any of the equipment, connect the units as a Wheatstone bridge. Pee-wee clips on the wires facilitate this procedure.

12. *Measurement of resistance.* Post-office type bridge; resistor; galvanometer; cell. Determine the resistance.

13. *Network resistance.* Five radio resistors with their resistances plainly marked and connected in some form, such as two in parallel with one, these being in series with the other two. Compute the total resistance.

14. *Milliammeter used as a voltmeter.* One or two B batteries concealed in a pulp board box and connected externally to a milliammeter of range 0 to 5 ma through a key and resistance box with appropriate plugs removed. The resistance of the meter is marked on the case. Determine the terminal voltage of the battery.

15. *Voltmeter with multiplier.* Set-up of No. 14, except that the milliammeter is replaced by a voltmeter of range 0 to 5 v. The resistance of the meter is marked on the case. Find the terminal voltage of the battery.

16. *Milliammeter with shunt.* A 0–5-ma meter is connected by special pee-wee clips to a wire, mounted on a meter stick, that serves as a variable shunt. This combination is in series with a rheostat, a key, a dry cell and a 0–500-ma meter concealed in a box. The resistance per unit length for the shunt is marked on the meter stick and the resistance of the 0–5-ma meter is also marked on the case. Press the key and from the reading of the 0–5-ma meter determine the reading of the concealed meter.

17. *Absolute measurement of current.* Tangent galvanometer in series with a suitable resistor, a key and a milliammeter concealed in a box. Calculate the reading of the ammeter. The student is expected to observe the number of turns in use on the galvanometer coil; the radius of the coil is marked on the name plate.

18. *Measurement of capacitance.* Ballistic galvanometer; *DPDT* switch; standard condenser; electrolytic condenser; charge-discharge key; cell. Determine the capacitance of the electrolytic condenser. The entire apparatus is set up so that students can measure the throw from a pair of standard condensers connected in series to one side of the *DTDT* switch while the unknown (generally electrolytic) is connected to the other side. Students tend to forget the significance of the two known condensers in *series*.

19. *Condenser networks.* Standard condenser with switches that permit five units of capacitance to be connected in various combinations. Determine the capacitance of the standard. In addition to this, tubular radio condensers, well marked, can be connected in networks as were the resistors in No. 13.

20. *Simple a.c. circuit.* Air-core coil of inductance about 0.2 h connected in series with a lamp and ammeter to a 110-v a.c. circuit; voltmeters connected across source, lamp and coil, respectively. Close the switch, read the meters and determine the inductance of the coil and the angle of lag.

21. *Switches.* Reversing switch with terminals labeled with letters; electromagnet; cell. Connect the cell and electromagnet so that the cell can be reversed.

22. *Focal length of a lens.* Optical bench on which is mounted a camera or projection lens such that the relationship $1/p+1/q=1/f$ cannot be used. Determine the focal length. The student is expected, without any suggestion, to take two positions and obtain f from $(L^2-A^2)/4L$, where L is the distance from the object to the screen and A is the distance between the two positions of the lens. The lens should be of such construction that the train of lenses is several centimeters long.

23. *Refractive index.* Microscope with vertical scale; plate of Lucite 1 cm thick. Determine the refractive index.

24. *Angle of prism.* Spectrometer with wooden prism; plane mirrors fastened to the prism with rubber bands. Find angle between mirrors.

25. *Minimum deviation.* Spectrometer; neon lamp. Set the instrument at minimum deviation for the yellow line in the neon spectrum. Students can find more rays coming through a prism than a physicist ever dreamed of before.

26. *Identification of spectrum.* Some source, such as a mercury arc, concealed in a box so that a spectrometer can pick up radiation from a slit in the box. Identify the spectrum.

27. *Microscope.* Microscope; millimeter scale. Determine the magnification.

28. *Telescope.* Telescope and tripod on table. Determine the magnification. The student, without any suggestion, is expected to use panes in the laboratory windows to compare the aided and unaided visual angles.

29. *Lenses.* Five numbered lenses placed on a piece of lens paper on the table. Pick out the two most suitable lenses for (*a*) a microscope and (*b*) a telescope.

30. *Radiofrequency measurements.* Oscillator, crystal-controlled, with frequency marked on chassis; calibrated condenser; radiofrequency ammeter; coil. Determine the inductance of the coil (distributed capacitance is neglected).

31. *Electronic instruments.* Cathode-ray oscillograph, arranged so that all of the controls need some adjustment. Adjust the instrument. Students generally time themselves in this operation.

The tests outlined are ones the author has used from time to time, but the experienced instructor interested in similar tests should have no difficulty in extending the idea to calipers of all kinds, trip scales, Joly balances, barometers, thermometers, polarimeters and other similar instruments.

Three Demonstration Experiments on Projectile Motion

Richard M. Sutton
Haverford College, Haverford, Pennsylvania

(1) The independence of the horizontal and vertical components of the velocity of a projectile is demonstrated after the manner of Experiment **M-99**[1] but, instead of using a small car with a spring gun to shoot the projectile vertically, a cart equipped with wheels (roller skates are convenient) is employed. The demonstrator sits upon the cart, coasts across the lecture room with speed V_h, and imparts vertical motion to the projectile by striking a simple catapult with a hammer (Fig. 1). He may thus propel the projectile high into the air while he is in uniform horizontal motion, and may catch the projectile either in his hand or in a catch pan surrounding the "cannon." The distance which he advances while the projectile is in flight is, of course, dependent upon his horizontal speed and upon the length of time that the projectile is in the air.

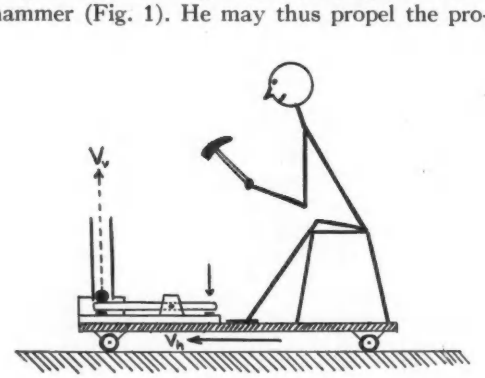

Fig. 1.

(2) The parabolic descent of a bomb dropped from an airplane is shown in slow motion by a simple method of "diluting the force of gravity." A model airplane suspended on rollers from a horizontal wire near the ceiling is drawn across the lecture room at constant speed (about 2 ft sec^{-1}) by a thread running over a pulley to a drum attached to a bicycle wheel. The wheel is driven by a belt around its periphery running to the pulley of a pump motor, or by any other convenient arrangement (Fig. 2). At a predetermined point a "bomb" is released from the plane but its descent, although with constant acceleration, is slow because the bomb is tied by a thread wrapped around the spindle of a small gyroscope top G mounted on the plane. The descending bomb accelerates the gyroscope, and its own vertical acceleration is thus limited to a small value. The thread is made just long enough so that when the bomb reaches the floor it is disengaged from the plane and is not raised again by the rapidly spinning gyroscope. The time of descent is controllable over wide limits by varying the mass of the bomb; 5 to 10 sec is convenient, during which time the plane advances 10 to 20 ft. The bomb may be conveniently dropped onto a target T on the floor whose position is readily determined in advance, either by trial or by computation.

The manner of release of the bomb is shown in Fig. 2: a mousetrap M mounted on the back side of the plane is arranged with a probe P to engage the spokes of the gyroscope top G when "set." The trap is sprung by pulling off a short sleeve S which holds the trap's trigger parallel to a bent nail in the base of the trap. This sleeve can be tied to the wall by a thread so as to spring the trap at the same point in the room time after time. Thus the motion is duplicable to a satisfactory degree. At the instant the trap is sprung, the demonstrator can call "*Bombs away!*" The target may consist of a box or carton into which the bomb is dropped; and for additional dramatic

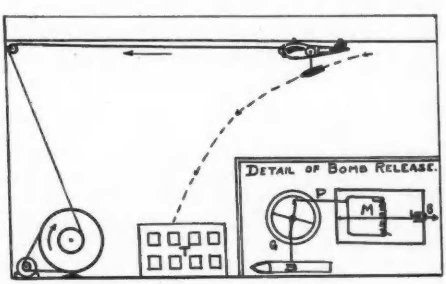

Fig. 2. Trajectory of a bomb.

[1] R. M. Sutton, ed., *Demonstration experiments in physics* (McGraw-Hill, 1938).

effect—not physically consequent upon the motion of the bomb unless more refined methods are employed—a charge of flashlight powder may be hidden inside the box, to be exploded electrically at the instant the bomb arrives.

(3) A "baby bazooka" to show rocket propulsion of a projectile is made by attaching a tubular tailpiece T (Fig. 3) with fins to a small cartridge of compressed carbon dioxide C, such as the cartridges used for charging siphon bottles (Fig. 3). The cartridge and tailpiece are adjusted to slide freely through a launcher tube L about 30 cm long which can be mounted rigidly in a clamp stand and aimed toward a safe part of the walls or out a window. The gas in the cartridge is released by impact of a firing pin P upon the seal S. Such a pin consists of a metal rod equipped with a steel phonograph needle, the metal rod fitting loosely within the tube of the tailpiece. When the firing pin is struck with a hammer, the response is immediate and violent: the projectile is shot from the tube with a speed of about 25 m sec^{-1}, and its range may be as much as 75 m. The launcher tube is open at both ends, and the projectile is propelled by the reaction of the

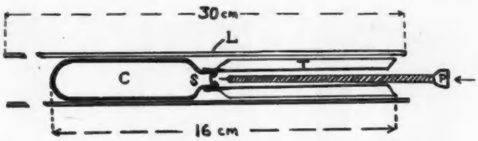

FIG. 3. The baby bazooka.

rapidly escaping gas. Certain energy and momentum aspects of the motion are of interest: the cartridge, whose mass (filled) is about 32 gm, contains approximately 8.5 gm of gas under a pressure in excess of 400 atmos. As the volume occupied by the gas is roughly 10 cm^3, the cartridge has more than 2500 j of potential energy! The kinetic energy imparted to the projectile is, however, less than 1 percent of this amount. The exact value depends, of course, upon the mass of the projectile. In one case, where the range was 75 m when the launcher tube was at 45° elevation, the mass of the projectile (cartridge plus tailpiece) was 45 gm before discharge. A cartridge without tailpiece was found to spin about aimlessly in an unreliable fashion.

Due caution in handling the projectiles and in demonstrating their motion is urged.

Diffraction Gratings at Low Cost

WARNER W. SCHULTZ
Reed College, Portland, Oregon

EVERY teacher of school or college physics would be happy to have a sufficient supply of diffraction gratings so that each student could have one or more available during the lecture on the subject. This paper describes a method by which gratings of small dispersion and producing brilliant spectra can be prepared at a cost not exceeding 10 or 20 cts per grating if a considerable number are made at one time. The work can be done by the students themselves, who will thereby acquire a better knowledge of diffraction, resolving power and photographic processes.

It is a familiar fact that diffraction gratings can be made by photographing a series of parallel lines. But the ruling of equally spaced lines is a laborious process if done without special equipment. It occurred to the author that accurately spaced lines could be secured by photographing the edge of a stack of paper made up of alternate layers of black and white sheets. The method is outlined below.

The paper was piled in a rack made of two flat pieces of wood fastened at right angles to each other. The rack was tilted so that the sides made angles of about 45° with the horizontal, one face was covered with a piece of plate glass, and the layers of paper were placed with their edges against this glass. When the stack of paper reached a thickness of 6 in. or more, it was placed with the edges vertical, the glass plate was removed and the stack was weighted or placed in a press. It was then ready to photograph. The number of black layers varied from 160 to 400.

Any camera with a highly corrected lens should

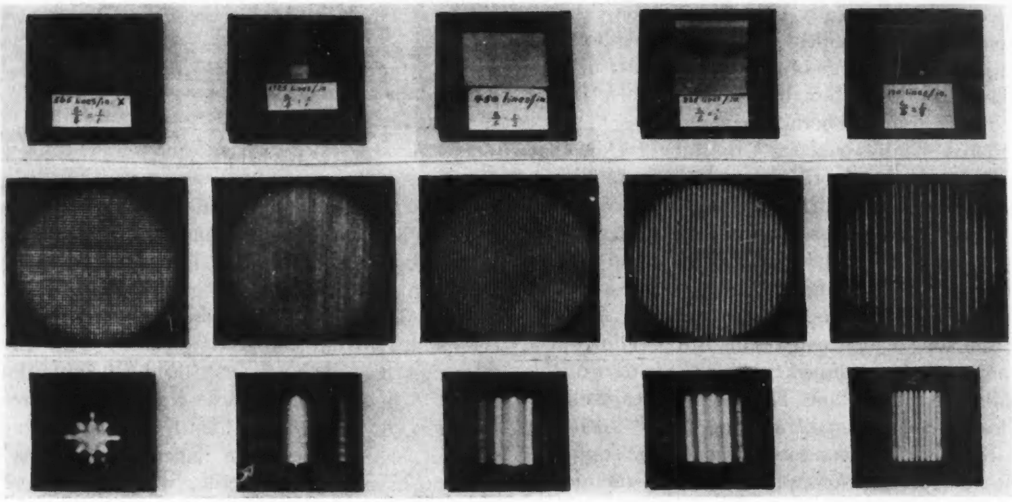

FIG. 1. *Top:* the finished gratings. *Middle:* photomicrographs of a portion of the gratings above. *Bottom:* the spectra produced by the gratings.

prove satisfactory. The greatest difficulty encountered is in the focusing on the lines formed by the paper sheets. Ordinary focusing methods are not accurate enough. A ground glass fine enough to serve can be made by grinding together two pieces of glass, using very fine carborundum (No. 600 or finer) with water. If a microscope or eyepiece is focused on the pitted surface of this ground glass screen, the image of the paper strips can be brought into focus by adjusting the camera. While such focusing will produce acceptable results, the following procedure was found to be an improvement.

Black lines of equal width are ruled on numbered strips of paper. The strips are mounted upright at intervals of 2 in. along the axis of the camera system, some between the stack and the camera, some beyond. When a picture is taken of stack and strips, examination of the film with a microscope will show which ruled line is in best focus and so will indicate what movement of the camera will give the best focus on the stack.

It is essential that a film of high resolving power be employed. Perhaps the most convenient material to use is a 2×2-in. lantern slide plate, for its grain is sufficiently fine for the purpose. Negative materials of higher resolving power, such as microfilm, can be used. (The Eastman Kodak Company has recently announced a plate having a resolving power of 500 lines/mm. Work is now in progress employing this new film, and it is hoped to produce gratings with 10,000 or more lines to the inch.)

Figure 1 shows, in the horizontal row at the top, the gratings themselves. The middle row shows photomicrographs of the lines on the gratings, and the bottom row shows spectra produced by placing the gratings in front of a camera lens with the camera focused on a source of light. The first grating in the series was made by exposing a plate, rotating it 90° and exposing it again. The source of light used to obtain the spectrum with this "crossed grating" was an ordinary incandescent bulb with a circular aperture between it and the camera. For the other spectra, a straight filament bulb served as a source.

As can be seen from the photograph, the number of lines per inch varies from 190 to 1725. The quantity a/b is the ratio of the number of black sheets to the number of white ones. The ratio of the transparent to the opaque part of the negatives obtained is not necessarily constant. Some control over this ratio can be secured by varying the time of exposure and development.

Not only are these gratings useful for direct

observation of spectra, but with a fairly large grating the spectrum can be projected so that an entire class can observe. For such projection, the grating is placed in front of the projection lens of a lantern, with a slit in the slide position.

The author wishes to express his appreciation to Dr. A. A. Knowlton, of Reed College, for his interest in this project.

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NOTES AND DISCUSSION

Concerning Some Terminology in Rotation

E. Scott Barr
Tulane University, New Orleans, Louisiana

ALTHOUGH the average student is quite familiar with such expressions as "events of great moment" and "momentous occasion," few of them associate the meaning "importance" with the word "moment" when they encounter the terms *moment of force* and *moment of inertia*. Consequently, these physical terms are at first more or less meaningless to the student—or, worse yet, are thought to be in some vague way associated with a time interval.

However, if the instructor points out this connotation of the word "moment"—which most textbooks fail to do—it then becomes a simple matter to demonstrate that the "moment," or "importance," of a given force in producing rotation must depend upon where and how the force is applied to the body.

In the same manner *moment of inertia* may be clarified. (A better term would be "moment of mass," *mass* being used in quantitative considerations.) Since *inertia* and *mass* are equivalent terms, the "moment"—that is, the importance—of this inertia is readily shown to be variable. This may well be done by considering the resistance to rotation offered by the same mass when the body is formed into different shapes or is moved relative to the axis of rotation.

This leads rather naturally into defining an "effective" distance of action for the mass in each case—the *radius of gyration*. Here, again, the writer would propose a change in terminology through replacing the antiquated *radius of gyration* by the simpler term, "effective radius."

Radius of Curvature Measurements

H. C. Schepler
General Motors Research Laboratories, Detroit, Michigan

IN the absence of a spherometer or other apparatus used in the numerous methods of measuring radius of curvature, the simple equipment described here may be found useful. One feature of this method is that, inasmuch as the distances measured in determining the radius of curvature are comparable in magnitude to the latter, it is possible to obtain results of fairly good precision by making all measurements with an ordinary steel scale.

As shown in Fig. 1, a source P and lens E are set up to give parallel light. The source P should approximate a point source—it may be an automobile headlamp bulb—and E should be of large diameter, such as a condenser lens. Lens F, the radius of curvature of whose surface S is to be found, is centrally placed in the parallel beam emitted from lens E.

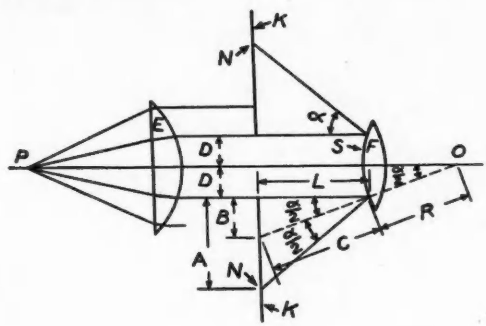

Fig. 1.

A card K having in it a hole of diameter $2D$ is placed in the parallel beam between lenses E and F. The magnitude $2D$ depends upon the diameter of lens F, and it should be small as compared with the diameter of lens E so that only the central portion of E is used.

A parallel beam, reflected from the surface of lens F as from a convex mirror, will illuminate an area NN on the back of the card K. Card K is adjusted so that this illuminated area is concentric with the hole $2D$. This adjustment can be facilitated by scale markings or concentric circles drawn on the card. Distances L and A are measured.

Since the line C (R extended) is the normal for reflection of the extreme ray as shown in Fig. 1, line C bisects the angle made by the extreme incident ray and its reflected ray from surface S. As is evident from Fig. 1, $R=D/\sin \frac{1}{2}\alpha$ and $\tan \alpha = A/L$. Thus R can be determined.

With L and D fixed, it is a simple matter to mark off card K in concentric rings calibrated in radii of curvature. For more than a temporary setup, with P, E and K properly located with respect to one another, fingers may be attached to K to support lens F at the fixed distance L from the card K.

This same setup may be used to check radii of curvature of concave surfaces of lenses by applying the well-known

concave mirror formula. A small card is placed in the beam between K and F and adjusted to locate the point of focus of the parallel rays reflected from the concave lens surface. Twice the distance from this card to the concave lens surface is its radius of curvature. The diameter $2D$ is significant only in that if it is too large with respect to the radius of curvature being measured, the caustic produced by reflection from a concave spherical surface will increase the error in focal length measurement in direct proportion.

When measuring cylindrical surfaces, a rectangular hole or wide slit is preferable to a round hole. The slit length will be $2D$ and the procedure is the same as for spherical surfaces.

Notes on Two Experiments

ARTHUR TABER JONES
Smith College, Northampton, Massachusetts

VAPOR pressure.—The pressure exerted by a saturated vapor is often demonstrated by introducing a small amount of some volatile liquid, say ether, into the Torricellian vacuum in a mercury barometer. Until recently I have often had difficulty in inserting the ether. The following device proves helpful.[1]

The U-tube in Fig. 1 is drawn from glass tubing with a

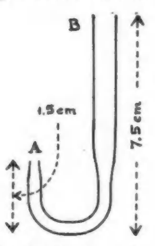

FIG. 1. U-tube for introducing ether

bore of about 6 mm. With A closed by a finger the tube is filled with ether. Then with B closed A is uncovered, passed down through the pool of mercury, and brought up inside the barometer tube to a level above that of the mercury outside. If the finger is now momentarily removed from B, the ether rises through the mercury. Incidentally, this method of introducing the ether illustrates the fact that at the level to which A is brought in the barometer tube the pressure is less than atmospheric.

Cleaning a barometer tube.—When cleaning a barometer tube—first with dilute nitric acid, then with distilled water, and lastly with alcohol—I find it helpful to insert a piece of No. 20 cotton-covered copper wire somewhat longer than the tube. When the nitric acid or water does not of itself move past air bubbles, manipulation of the wire aids in filling and emptying the tube.

Achromatic interference fringes.—It is well known that with a source of white light Lord Rayleigh[2] obtained achromatic interference fringes by using a narrow slit, a grating or prism and a Lloyd mirror. The present note points out that similar fringes may be obtained by making use of the chromatic aberration of an ordinary lens instead of the rather special grating or prism usually employed.

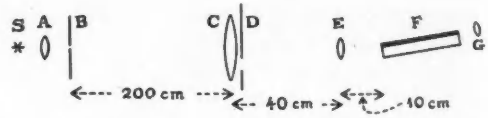

FIG. 2. Apparatus for obtaining achromatic fringes, as seen from above.

The grating that Rayleigh used had about 235 lines/mm, and with his apparatus he says that "a comparatively rough adjustment . . . is sufficient to render . . . distinct the first 20 or 30 bands. As the adjustment improves, a continually larger number become visible, until at last the whole of the doubly illuminated field is covered with fine lines." When repeating the experiment it has been recommended[3] that a grating with a wider spacing be employed, say some 20 to 100 lines/mm. Such a grating gives a shorter spectrum, and so makes it easier to obtain fringes that do not crowd so closely together.

Rayleigh also obtained an approximation to achromatic fringes by using instead of a grating a prism with a refracting angle of about 20°. In this case he says that "the number of black and white bands to be observed is not so great as might perhaps have been expected."

In many laboratories a grating with only some 20 to 100 lines/mm, or a prism with a refracting angle in the neighborhood of 20°, is probably not immediately available, but I have found it possible to obtain a considerable number of fairly achromatic fringes by replacing the grating or prism by part of an ordinary lens. In Fig. 2, S is a source of light, and B a narrow slit on which the light is focused by the lens A. C is a 4-diopter lens 5 cm in diameter, and D a piece of black paper containing a rough slit about 1×2 cm, with its shorter dimension in the plane of the figure. The middle of the slit is not on the axis of C, but, as shown in the figure, is approximately halfway to its edge. E is a 20-diopter lens, F a sheet of black glass about 20 cm long and G an eyepiece. The distances indicated in Fig. 2 are not at all critical. The adjustment is not difficult, and when it is satisfactory the field of the eyepiece is nearly filled with some 20 to 40 fringes that show little color. The fringes toward the face of the mirror F are beautifully distinct and clear. Farther away they become fainter and more washed out, and begin to show color.

The precise width of the slit in D is not important. It is even possible to get good fringes with the screen D removed and the whole lens exposed. If, however, the slit is too narrow the fringes are not achromatic. With a slit width of 1 mm the number of fringes is considerably reduced, and they are vividly colored, the hue changing greatly as the mirror is moved slightly across the path of the light.

The distance of the slit from the axis of the lens C proves also to be not at all critical. The slit may be close to the edge of the lens or nearer its center without any great change in the fringes. With the apparatus arranged as in Fig. 2, the entire half of the lens C on the side toward which the mirror faces may be covered or not, but a part, at least, of the other half must be exposed.

It is possible to get good fringes without the lens *E*. The mirror is then turned to face the other way, and is brought closer to *C*. But the fringes are now fewer, and do not so nearly fill the field of the eyepiece.

[1] Perhaps something similar to the tube shown in Fig. 1 is intended in R. M. Sutton's *Demonstration experiments in physics* (McGraw-Hill, 1938), p. 218, where it is suggested that the liquid be inserted "by means of a curved pipette or dropper." Another method, pointed out by Professor John Zeleny, is to put a little of the volatile liquid on top of the mercury before the tube is inverted, and thus avoid the need for using a pipette; however, he considers the pipette method better if the liquid is to be introduced before a class.

[2] Rayleigh, Phil. Mag. 28, 77, 189 (1889).

[3] R. W. Wood, *Physical optics* (Macmillan, 1934), p. 181; A. W. Barton, *A text book on light* (Longmans, Green, 1939), p. 294.

Newton's Third Law of Motion

MORTON MOTT-SMITH
Science Service, Washington, District of Columbia

IN a recent article[1] Professor George A. Lindsay pointed out certain misconceptions that have appeared in physics textbooks concerning Newton's third law of motion. Chief of these misconceptions is the idea that the action and the reaction take place in the same body, an idea which makes it difficult to distinguish the relation of action and reaction from the condition for equilibrium of two forces. The idea is fostered perhaps by the illustration given by Newton himself of a horse dragging a stone, or other heavy object, along the ground by means of a rope. From the way in which the operation is sometimes described, it would appear that the action takes place at the end of the rope where the horse is pulling, and the reaction at the other end where the stone is said to be pulling back equally hard. It has always been difficult to imagine how the inert stone could be pulling on the rope just as actively (or reactively) as the struggling horse at the other end. And if they are both pulling equally, why is there any motion, or change of motion, at all?

I think Newton's statement that to every action there is always opposed an equal reaction, is partly responsible for the confusion. It suggests that forces always occur in pairs which are equal in magnitude and opposite in direction. Of course, the two forces do not oppose each other because they act on different bodies, as Professor Lindsay pointed out. And the statement "Action and reaction are equal and opposite" says nothing about there being two forces but leaves one to suppose that one and the same force produces two effects—equal and opposite. This is contrary to the second law, which attributes to each force one effect—an acceleration in the direction in which it acts.

The real essence of the third law is that what we have always to deal with is an interaction between two bodies, which either pulls them toward each other or thrusts them apart. Thus, gravitational attraction pulls the earth and the sun toward each other, and each receives an acceleration inversely proportional to its mass.

To an observer on the earth it appears that a centripetal force, exerted by the sun, pulls the earth toward the sun. To an observer on the sun it would appear that a centrifugal force, exerted by the earth, drags the sun away from a central position. We have to assume two oppositely directed forces to account for the two accelerations. But these are simply the way the thing looks to observers situated at opposite ends of the line of interaction.

Which of the two accelerations you will relate to the action and which to the reaction depends merely on which one you are the more interested in, and often on which is the larger. In reality they are coordinate, not one subordinate to the other. When a soldier fires his rifle, he is primarily interested in the action on his bullet, and so the force on the gun becomes the reaction. If rocket ships should ever become common, we would probably reverse the terms, and consider the force on the ship as the action, the force on the propelling gases as the reaction, just as we now say that the impulse turbine is driven by the action of the deflected gases.

The custom of using vectors in diagrams to indicate the forces acting on a body is apt to make us forget that in addition to the body acted upon, there is always another body that does the acting, or which together with the first body is responsible for the existence of the force. A force does not just exist in and by itself, just pulling off into space as the arrow would indicate. Every force is exerted by a body on a body. And which we choose to say is the acting body and which the body acted upon, is quite immaterial.

The vector in the diagram thus tells only half the story although, to be sure, it is the half in which we are interested. So long as the manner in which the forces acting have arisen does not affect the problem, we may safely ignore the other half. But I think that we should never forget that it exists—like the aviator the soldiers tell about who shot off his big cannon, whereupon his plane parted in the middle. "Oh dear," he exclaimed, "I forgot about the recoil."

In elementary physics courses, Newton's third law has always been a sort of stepchild. After the student has learned about the first and second laws, and perhaps the use of vectors, the third law is introduced almost like an afterthought. A few examples are given, after which scarcely anything more is heard about it. Yet the third law is the most fundamental of the three, since it introduces the basic fact that we have always to do with interactions between bodies. It does not matter whether we attribute the resulting accelerations to the action of forces or to the curvature of space. After all, the second law tells us only how to measure a force after we have decided upon it as the cause of the acceleration. And the first law is a special case of the second.

It might be clearer, and would at least be more logical, to reverse the order of the three laws, thus passing from what is directly observable, the accelerations, to the theory which is adopted to account for them. If this is not done, then at least the third law should be given fuller and more careful treatment, and its universality distinctly pointed out. In either of these ways, I think, many misunderstandings would be avoided. These ideas are not new but, in my opinion, too little used.

[1] "Newton's third law of motion as presented in textbooks of physics," Am. J. Phys. 11, 319 (1943).

Proceedings of the American Association of Physics Teachers

The New York Meeting, January 13–15, 1944

THE thirteenth annual meeting of the American Association of Physics Teachers was held at Columbia University, New York City, on January 13 to 15, 1944. The presiding officers were L. W. Taylor, President of the Association, and R. C. Gibbs, Vice President. Professor Gibbs was also chairman of the program committee for the meeting.

A joint dinner with the American Physical Society and the Electron Microscope Society of America was held at the Men's Faculty Club of Columbia University on Friday evening, January 14. After the dinner about 60 members of the societies participated in an informal conference on deferment of physicists which was ably led by Lt. Col. Walter Mendelsohn, of the Manpower Division, National Selective Service Headquarters.

Invited Papers

The session on Friday afternoon, January 14, held jointly with the American Physical Society, was devoted to five invited papers relating to war training programs and manpower problems in the field of physics:

ASTP, past, present and future. T. D. PALMER, Lt. Col., USA. Deputy Director, AST Division.

Manpower problems in physics, present and future. H. T. BRISCOE, Indiana University, Chief of the Professional and Technical Division of the Bureau of Training, War Manpower Commission.

College standards as reflected in the V-12 program. A. C. EURICH, Commander, USNR, Officer in Charge, Standards and Curriculum Section.

Continued need of the Navy for officer personnel. JOHN M. DARLING, Office of Naval Officer Procurement.

The physics war front in Washington. HOMER L. DODGE, Director, Office of Scientific Personnel, National Research Council.

This symposium was followed by a general discussion of the Army training program, led by T. H. Osgood, of Michigan State College, and of the Navy training program, led by R. B. Lindsay, of Brown University.

Contributed Papers, with Abstracts

Two sessions were devoted to the following contributed papers:

1. Physics problems for Army Air Crew students. PAUL F. BARTUNEK*, *Allegheny College*, AND J. N. SNYDER, *University of Maryland*.—Air Crew students who fail to make the effort necessary to master elementary physics because they see no immediate association of the subject with aeronautics have their interest aroused at once if aviation examples of fundamental physical principles are brought to their attention. We have accordingly designed a set of problems intimately connected with aviation to be used as a supplement to the textbook. The result has been that the students are more alive in class, ask more questions and in general make a greater effort to understand the basic principles than they do if the more conventional type of problem is used. Upon perusal of literature relating to airplanes and aerodynamics an abundance of problems in every phase of physics will suggest itself to the resourceful teacher.

* Now at the University of Maryland.

2. Principles of physics in the courses taken by midshipmen. WALTER E. PETERSON, *U. S. Naval Reserve Midshipmen's School, Columbia University*.—Midshipmen in training for commissions as deck officers take courses for which they should have a good background in physics and mathematics. Since many are lacking in this, considerable time has been consumed in teaching the necessary principles. However, with physics now required in the V-12 program, it is expected that future midshipmen will be better prepared than those we have had. Of greatest value is an understanding of mechanics, particularly of angular and periodic motions, and gyroscopic precession. The elements of heat transfer and of thermodynamics are needed to understand power plants. Little in electricity is needed beyond the meaning of common units and the treatment of current in parts of series and parallel circuits. The physics teacher should teach principles but leave naval applications to instructors in the naval schools. Moreover, a good understanding of principles will be of greater value than ability to derive equations or to solve complex problems.

3. The pre-laboratory quiz. C. J. OVERBECK, *Northwestern University*.—The Navy V-12 course in college physics as given at Northwestern University allows only 2 hr/wk laboratory time including the write-up. Recognizing that an unprepared student would accomplish little in this time, we give a pre-laboratory quiz at the beginning of each session to encourage preparation. The laboratory instructor selects two of the following five questions to be answered in writing (3 to 4 min.) by each student: (i) What is the object of today's experiment? (ii) Give a concise statement of the experimental procedure; (iii) What important physical law applies to this experiment? (iv) State a practical application of the phenomenon involved; (v) Where must you use the greatest care in taking data, and

why? The results obtained are gratifying; the students apparently recognize the value to them of this quiz. Its successful operation depends on the facts that (*a*) the students know the five questions in advance and have a definite goal in preparation, (*b*) the examination is given each time, and (*c*) the grade is a part of the laboratory grade. We also use this plan now in the Liberal Arts and Technological Institute courses.

4. On the experiment of the dissectible Leyden jar. B. GROSS, *National Institute of Technology and Polin Laboratories* (*Rio de Janeiro, Brazil*).—The dissectible Leyden jar experiment is ordinarily considered to show "that the electric energy is stored up in the dielectric and not in the plates or only to a very small degree in the plates." While the conclusion is true, it may no be logically derived from the experiment as ordinarily performed. Were it the necessary conclusion, we should expect that a similar experiment performed with a gas or a liquid, rather than a solid, as a dielectric would end with the familiar intense spark. However, such sparks would not generally, if ever, be realized. Experiments with capacitors having solid dielectrics show two distinct effects of importance here: (i) ionic conduction inside the dielectric combined with the formation of high resistive layers near the electrodes, and (ii) hindered orientation of the dipoles in polar substances. When and only when one of these effects is present, is the intense spark of the dissectible Leyden jar experiment obtained. These effects are only secondary, however, so far as the energy in the dielectric is concerned. Consequently, they cannot demonstrate that the energy of a charged capacitor resides in the dielectric.

5. Coulomb's law and the dielectric constant. CARLETON C. MURDOCK, *Cornell University*.—Wilberforce[1] has called attention to the fact that the introduction of the permeability into the denominator of Coulomb's law of magnetostatics is incorrect. Several papers[2] on the topic were published between 1933 and 1935. A survey of textbooks published since that time shows, however, that in a majority of them the incorrect equation is used as the starting point for the subject of magnetostatics. The corresponding equation of electrostatics is valid under certain special conditions, but an analysis of these conditions shows that they apply to cases for which there is no magnetostatic analogy. Many recent textbooks base the subject of electrostatics upon this equation and draw from it conclusions not justified in view of its limited validity. It is suggested that the Association should undertake the investigation of this question in order to clear up the misunderstanding that seems to exist with regard to it.

[1] L. R. Wilberforce, Proc. Phys. Soc. London **45**, 82 (1933).
[2] L. Page, Phys. Rev. **44**, 112 (1933); L. R. Wilberforce, Proc. Phys. Soc. London **46**, 312 (1934); Page and Adams, Am. J. Phys. **3**, 51 (1935).

6. Electron flow as current. S. W. CRAM, *Kansas State Teachers College*.—The conception of the current in a metallic conductor as an electron drift, as used by Nilson and Hornung,[1] has been somewhat extended and adapted by the author for use in six college physics and radio classes, four ESMWT radio classes and nine Army Air Corps physics classes. The attendant explanations necessitate making a left-hand thumb rule right, and changing the motor and generator rules. Explanations of battery, meter and radio circuits, and of electrolysis are more direct. The instructor feels that he is released from the shackles of a heritage that has burdened physics instruction for too long a time. It appears unnecessary to wait for textbook writers to make this change as students seem to enjoy making the correction in their books. Results of tests over this phase of instruction show considerable improvement in learning, due undoubtedly to the lack of confusion as to what constitutes a current and the fact that the student's attention is more definitely called to this material for study.

[1] Nilson and Hornung, *Practical radio communication*.

7. A plan for eliminating the weight-mass confusion. A. G. WORTHING, *University of Pittsburgh*.—The plan accepts established double usages for the terms ***kilogram*** and ***pound***. It includes three general procedures. As based on the mks (changes appropriate for the cgs system are obvious) and the fps systems, they are as follows: (1) Use principally the distinctive terms and abbreviations, ***newton*** (n), ***kilogram-weight*** (kgwt) and ***pound-weight*** (lb) when reporting weights and forces; use principally the ***kilogram*** (kg) and the ***pound*** (pd) when reporting masses. (2) For consistency of equation-forms and for a tie between the two systems of units, introduce the *grav* as an acceleration unit to yield as defining equations,

$$1\ \text{n} = 1\ \text{kg} \times 1\ \text{m/sec}^2,$$
$$1\ \text{kgwt} = 1\ \text{kg} \times 1\ \text{grav} \doteq 1\ \text{kg} \times 9.8\ \text{m/sec}^2,$$
$$1\ \text{lb} = 1\ \text{pd} \times 1\ \text{grav} \doteq 1\ \text{pd} \times 32\ \text{ft/sec}^2.$$

(3) Refrain from confusing usages of the terms, "weigh," "weighing" and "weight." This means that, though we shall continue to "weigh" bodies when using spring balances, we shall henceforth "mass" bodies with equal arm balances using "lugs," not "weights," as standardized bodies of known masses, and refer to the process as "massing." With consistent use of the outlined procedures by authors and teaching staffs, one may reasonably hope that the weight-mass confusion will disappear.

8. Graphical methods in circuit analysis. P. I. WOLD, *Union College*.—Graphical methods, in contrast to conventional analytic methods, for calculating the currents in or the voltage drop over branches or groups of branches in circuit networks is capable of considerable extension. This may be advantageous from a pedagogic viewpoint and in some cases is economical of time. The author discussed the application of such graphical methods to typical nonreactive circuits with linear resistance elements.

9. A call for a more effective editing of textbooks while still in manuscript. THOMAS D. COPE, *University of Pennsylvania*.—As evidence of the great need for more effective editing, the following examples taken from textbooks in current use were cited: (i) a rigid body whose center of mass accelerates under a couple; (ii) a faulty definition of

volume modulus of elasticity; (iii) a misleading statement about elastic impact; (iv) an "equation" between mass and weight; (v) a "proof" that fails to prove; (vi) a specimen of terminology that does violence to the English language. Similar exhibits without number could be assembled. It is recommended that, as a part of our program to expand, re-examine and improve instruction at the college level, an agreement be reached with publishers of textbooks to the effect that manuscripts submitted for publication shall receive a far more effective critical reading than appears to be the current practice. A list of competent and responsible critics should be compiled and made available to the publishers.

10. A laboratory experiment illustrating the underlying principles of the searchlight. A. G. WORTHING and JOSEPH CYPHERS, *University of Pittsburgh*.—The illumination within the central cone of a searchlight beam is equivalent to that produced by a light source filling completely the mirror and having as its brightness that of the actual source multiplied by the reflectance of the mirror. As from ordinary sources, the illumination varies inversely as the square of the distance. The essential apparatus consists of a parabolic mirror, a photoelectric illumination meter, an incandescent lamp with properly frosted bulb, and a disk somewhat larger in diameter than the mirror and opaque except for a central circular opening whose cross section is that of the lamp. The reflectance is obtained by comparing, at a convenient point, the illumination due to the lamp alone, with the mirror blocked out, with that due to light reflected from the mirror when the screen is placed to block out direct light from the lamp but to yield for the illumination meter an apparent, uniform source of the same size and at the same distance as the lamp. With the lamp at the principal focus of the mirror, the central cone of the beam is readily determined as the region from which the mirror is seen completely filled with light. For points within the cone, one compares computed and measured illuminations.

11. Elementary experiments with lenses to study reflection and refraction at spherical surfaces. WALDEMAR NOLL, *Berea College*.—The familiar multiple images observable in lenses may be used to study refraction and reflection at spherical surfaces. In the case of a biconvex lens, two images, one real and one virtual, may be seen from the object side. The virtual image is formed by the first surface acting as a convex mirror. The real image is formed by refraction at the first surface, reflection at the second surface and then refraction at the first surface. The formulas for mirrors and for refraction at surfaces[1] are used to calculate the positions of the images. These may be experimentally verified on an optical bench. This same general procedure may be applied to lenses with various combinations of plane, convex and concave surfaces. With this method it is possible to study successive reflections and refractions at spherical surfaces using only simple equipment.

[1] Robertson, *Introduction to physical optics* (Van Nostrand, ed. 2), chaps. LV and V.

12. Projection device for illustrating longitudinal standing waves. J. H. HOWEY, *Georgia School of Technology*.—A small, convenient device has been designed to project a row of bright spots on a wall in such a way that their slow motion will illustrate the movement of particles in a longitudinal standing wave. It is similar to the Crova disk, but modified to illustrate standing waves and differing from available Crova disks in that it is adapted for projection with an ordinary lantern.

13. Nomogram for representing the Balmer formula. IRA M. FREEMAN, *Princeton University*.—The complete paper will appear in the next issue.

14. Content of high school physics course. S. W. CRAM, *Kansas State Teachers College*.—The report of Havighurst and Lark-Horovitz,[1] as well as other reports on war training in physics, shows remarkable results in preparing necessary personnel for industry and military service. In view of the present situation, however, we should examine the possible future of physics in the postwar high school. In some of the Kansas high schools the courses now being taught include high school physics, popular physics, vocational physics, automotive physics, radio, aeronautics and advanced general science (with emphasis on physics in the war). As many as four of these courses are being taught by the physics personnel in one school system. The author has given thought to some plans that may be of help in salvaging parts of these dangling elementary approaches for a program which will have the interest, content and attractiveness wanted and deserved by physics in the world to come. Obviously, if we are to have a populace conscious of our physical world, our most important task is to have a well-directed presentation in the elementary and secondary schools.

[1] Havighurst and Lark-Horovitz, Am. J. Phys. 11, 103 (1943).

15. A laboratory method for the study of projectile motion. CLINTON JONES AND H. MACK THAXTON, *Agricultural and Technical College of North Carolina*.—An apparatus for verifying the laws of projectile motion and studying the parabolic path of the projectile has been developed. It consists of a spring gun and trigger mechanism so mounted as to permit varying angles of elevation and rotation in azimuth. The range can be adjusted by changing the spring or by means of a screwhead for adjusting the tension of the spring. Velocities from 800 to 1500 cm/sec are possible with ranges up to 20 m. A laboratory model permits the study of the parabolic trajectory. The length of the latus rectum and the coordinates of the focus and vertex can be determined and compared with experiment. A trigger mechanism permits firing of the projectile electrically so that the time for range can be accurately determined. Independent checks on the velocity by other methods differ by a maximum of 20 cm/sec.

16. A consistent use of the term "slug" in an engineering physics textbook. LAWRENCE E. KINSLER, *U. S. Naval Academy*.—In revising the physics textbook used at the U. S. Naval Academy it was decided that problems in-

volving British units should be solved in gravitational units only. Usually this procedure necessitates two parallel sets of dynamical equations: one based on $f=ma$, used in the absolute metric system; the other based on $f=(W/g)a$, used in the British gravitational system. Instead, when, these two equations are first introduced, it is shown that substituting for W and g separately in the second form is equivalent to expressing the mass m in slugs in the first form. Thus, in the solution of problems involving equations based on $f=ma$, the student is presented with two alternatives. He may either employ the usual form of the equation and express mass in slugs or replace m by W/g and separately substitute values for W and g. It is hoped that this treatment will reduce the difficulties which the beginner experiences with the mystifying factor g.

17. Two demonstration experiments on projectile motion. R. M. SUTTON, *Haverford College.*—The complete paper appears elsewhere in this issue.

18. Samples *versus* survey in physics courses for liberal arts students. ERIC M. ROGERS, *Princeton University.*—For students who will not continue in physics, a plea is made for a general course to consist of samples rather than a comprehensive survey. A crowded survey produces too formidable an array of facts and leaves the students convinced that the knowledge behind the physics they have studied is mysterious and difficult rather than sensible and reasonable. Ruthless omission of sections of the usual syllabus—giving time for careful treatment of samples—may do better service to the students and to the good name of physics. Samples, treated in class and laboratory, can give real understanding if they provide clear, separate examples of the uses of facts, of concepts, of experimental methods, and, with very careful choice, of theories.

19. Comments on the teaching of college physics by nonphysicists. W. WENIGER, *Oregon State College.*—The complete paper appears elsewhere in this issue.

20. The Army Specialized Training Program. FRANK P. GOEDER, *Colorado State College of Agriculture and Mechanical Arts.*—This paper presents an account of the problems encountered in a typical college in preparing for a unit of the ASTP, and how they were solved. Liberal use was made of "retooled" teachers from other departments. The organization of the laboratory work is described in some detail. The *Cooperative Physics Tests* were used, and the results have been analyzed. When allowance was made for certain handicaps due to housing and to adjustment, the tests indicated average attainment by students.

21. The part that physics plays in the Navy. F. K. ELDER, *U. S. Naval Academy.*—The complete paper appears elsewhere in this issue.

Report of the Secretary

The executive committee of the American Association of Physics Teachers held its annual meeting in New York City on January 13, 1944. Members present were: L. W. Taylor, presiding; R. C. Gibbs, C. J. Overbeck, Louise S. McDowell, K. Lark-Horovitz, Gladys A. Anslow, Paul Kirkpatrick, A. G. Worthing, Duane Roller, W. H. Michener and R. F. Paton. New members of the committee present and those attending by proxy were: W. Noll, W. Weniger, L. I. Bockstahler, F. L. Talbott and F. P. Goeder. Other members of the Association present by invitation were H. A. Barton, F. L. Brown, J. W. Buchta, T. D. Cope, W. P. Davey and H. L. Dodge.

Reports were made by the officers and the chairmen of committees. R. C. Gibbs, chairman of the Membership committee, reported that some 90 new members had been added during the year. K. Lark-Horovitz, chairman of the Cooperative Action committee, presented a summary of the activity and plans of his committee. The motion that this report be approved was seconded and unanimously passed. Reports were heard from the chairmen of the committees on Awards, Richtmyer Memorial Lecture, Terminology, Letter symbols and abbreviations, and Engineering education. All committees were authorized to continue work in 1944.

It was voted to instruct the Association President for 1944 to appoint, if he finds it desirable, two new committees to consider (1) means of correcting confusion in concepts such as weight and mass and (2) the confusion associated with Coulomb's law and the dielectric constant.

Upon recommendation of the editor of the AMERICAN JOURNAL OF PHYSICS, H. W. Farwell, Rose C. L. Mooney and R. J. Stephenson were appointed associate editors for the period 1944–1946. A motion was passed instructing the President to appoint a committee to act with the editor in formulating policies on financing the journal.

Our representatives on the American Council on Education, R. M. Sutton, K. Lark-Horovitz and R. C. Gibbs, and our representatives to the American Association for the Advancement of Science, W. P. Davey and L. W. Taylor, and its Pacific Coast Division, L. E. Dodd and P. Kirkpatrick, submitted their reports. It was voted that these men continue as our representatives for 1944.

H. A. Barton, at the invitation of the chairman, gave a brief progress report on financing the purchase of the new building of the American Institute of Physics. L. W. Taylor was nominated to succeed A. G. Worthing as a representative of the Association upon the Governing Board of the Institute. Our three representatives at present are P. E. Klopsteg, T. D. Cope and L. W. Taylor.

The secretary stated that all eight Regional Chapters had filed reports for 1943. The petition of the Physics Club of Philadelphia for recognition as a Regional Chapter

was presented. This recognition was unanimously given. The Philadelphia Chapter thus became our ninth regional chapter.

Three Regional meetings were planned during 1943, and two of these were held—one at Pennsylvania State College, concurrently with the American Physical Society, and one at Chicago, jointly with the Society for the Promotion of Engineering Education [see Am. J. Phys. **11**, 232 (1943)]. The third meeting, planned for Oregon State College, was cancelled because of transportation and housing difficulties.

President Taylor reported on an emergency plan for holding regional meetings this year. All the Regional Chapters had accepted this plan and sent delegates to the annual meeting.

The question of methods to advance the use of our scientific literature in the Latin American Countries was referred to the Governing Board of the American Institute of Physics.

It was voted to accept the invitation of the Society for the Promotion of Engineering Education to meet jointly at Cincinnati, Ohio, June 22–25. It was also passed that we accept the invitation of the American Physical Society to join in a June meeting.

The report of the chairman of the Nominating committee, J. G. Winans, was placed on file. J. H. Howey and F. G. Tucker were appointed as tellers for the annual election.

The annual business meeting.—The thirteenth annual business meeting was held in the Pupin Physics Laboratories, Columbia University, at 10:15 A.M., January 15, 1944. President Taylor presided.

At the request of the president, the secretary gave a summary of the action taken by the executive committee at the meeting held on January 13. Comments on the action and business of the committee were made by the president. The report of the secretary was approved.

After hearing the report of the tellers, the chair ruled that the annual election had resulted as follows:

President: L. W. Taylor
Vice-President: Louise McDowell
Members of Executive Committee: J. W. Buchta, R. F. Paton.

A vote of gratitude was extended to R. C. Gibbs for the excellent program planned for the annual meeting.

C. J. OVERBECK, *Secretary*

Attendance

The following 118 members registered at the New York meeting:

Gladys Anslow, Smith College; B. W. Bartlett, U. S. Military Academy; H. A. Barton, American Institute of Physics; Vola P. Barton, Goucher College; P. F. Bartunek, University of Maryland; T. A. Benham, Haverford College; C. E. Bennett, University of Maine; W. H. Billhartz, Franklin College; H. Louisa Billings, Smith College; L. I. Bockstahler, Northwestern University; R. A. Boyer, Muhlenberg College; H. Branson, Howard University; G. P. Brewington, Lawrence Institute of Technology; F. L. Brown, University of Virginia; J. W. Buchta, University of Minnesota; W. S. Burton, George School; E. C. Campbell, Princeton University; G. M. Carlton, Drexel Institute; H. R. Childs, University of Rochester; B. Cioffari, Princeton University; T. D. Cope, University of Pennsylvania; S. W. Cram, Kansas State Teachers College; W. P. Davey, Pennsylvania State College; H. L. Dodge, National Research Council; D. C. Duncan, Pennsylvania State College; J. A. Duncan, U. S. Naval Academy; J. R. Dunning, Columbia University; R. J. Dwyer, Trinity College.

V. E. Eaton, Wesleyan University; F. Elder, U. S. Naval Academy; H. W. Farwell, Columbia University; A. Gaudin, Brooklyn, New York; R. C. Gibbs, Cornell University; P. R. Gleason, Colgate University; F. P. Goeder, Colorado State College; C. Goodman, Massachusetts Institute of Technology; H. Gurd, Bucknell University Junior College; A. N. Guthrie, Brooklyn College; V. B. Hall, Wilkes-Barre, Pa.; D. T. Hamilton, Denison University; M. C. Harrington, Drew University; S. M. Heflin, Virginia Military Institute; C. L. Henshaw, Colgate University; Erna Herrey, Queens College; M. E. High, Princeton University; J. H. Howey, Georgia School of Technology; H. H. Hubbell, Jr., Amherst College; G. F. Hull, Dartmouth College; M. C. Hylan, University of Colorado; Bro. Godfrey John, LaSalle College; C. F. Johnson, Jr., Watertown, Conn.; G. E. Jones, Atlantic Union College; Sister Maria Jose, Immaculate College; E. C. Kemble, Harvard University; C. Kikuchi, Haverford College; L. E. Kinsler, U. S. Naval Academy; H. Kirkpatrick, Arlington, Mass.; P. Kirkpatrick, Stanford University; S. Kusaka, Smith College; L. C. Langguth, Fairfield College Preparatory School; D. P. LeGalley, Philadelphia College of Pharmacy and Science; R. B. Lindsay, Brown University; W. N. Lowry, Bucknell University.

D. G. MacGregor, Mount Allison University; K. V. Manning, Pennsylvania State College; Sister Anastasia Maria, Immaculate College; Iona Mario, University of Chicago; A. E. Martin, New York City; Louise McDowell, Wellesley College; Helen Messenger, Hunter College; W. H. Michener, Carnegie Institute of Technology; Beatrice Miller, Philadelphia, Pa.; L. B. Morse, College of the City of New York; C. C. Murdock, Cornell University; W. Noll, Berea College; J. S. O'Conor, St. Joseph's College; H. N. Otis, Hunter College; T. H. Osgood, Michigan State College; C. J. Overbeck, Northwestern University; R. F. Paton, University of Illinois; W. E. Peterson, Midshipmen's School, Columbia University; F. R. Pratt, New Jersey College for Women; M. J. Pryor, Amherst College; C. H. Raynor, Roanoke College; E. Ritchie, De Pauw University; G. D. Rock, Catholic University; E. M. Rogers, Princeton University; D. Roller, Hunter College; E. I. Salkovitz, Naval Research Laboratory; H. K. Schilling, Pennsylvania State College; F. W. Sears, Massachusetts Institute of Technology; R. S. Shaw, College of the City of New York; L. E. Smith, Denison University; R. H. Snyder, Mississippi State College; J. E. Spike, Jr., Ogden Memorial Laboratory; M. N. States, Central Scientific Company; Hildegard Stucklin, Sweet Briar College; R. H. Sutton, Haverford College; F. L. Talbott, Catholic University; L. W. Taylor, Oberlin College; D. Telfair, Springfield, Mass.; Agnes Townsend, Barnard College; M. H. Trytten, University of Pittsburgh; F. G. Tucker, Oberlin College; Katherine Van Horn, New Jersey College for Women; F. C. Vonder Lage, U. S. Naval Academy; B. B. Watson, University of Pennsylvania; R. C. Weaver, Virginia Military Institute; Dorothy Weeks, Wilson College; M. R. Wehr, Drexel Institute of Technology; W. Weniger, Oregon State College; A. O. Williams, Jr., Brown University; J. G. Winans, University of Wisconsin; B. F. Wissler, Middlebury College; A. G. Worthing, University of Pittsburgh; W. R. Wright, Swarthmore College; J. Zeleny, Yale University; Charlotte Zihlman, Barnard College.

Forthcoming meetings. Regional Chapter of the District of Columbia and Environs, George Washington University, Washington, D. C., April 22, 1944; Southeastern Section, APS, Atlanta, Ga., May 5–6, 1944.

DIGEST OF PERIODICAL LITERATURE

A Demonstration of Independent Measurement

Few, if any, student experiments are directed to demonstrating that the "fundamental" or "independent" measurement of a magnitude, involving addition and requiring no prior measurement of any other magnitude, is sometimes, but not always, possible. One reason for this neglect of a fact that lies at the root of all experimental physics may be the difficulty of choosing a suitable magnitude as an illustration. If length or mass were chosen, a demonstration that certain conditions have to be fulfilled would be unconvincing because the student is too familiar with the measurements involved. Yet, an attempt to illustrate the fact in some field where the failure of addition leads to real difficulties—for example, heterochromatic photometry—would fail because the situation is too complex and unfamiliar.

This dilemma might be avoided by concealing from the student that the magnitude he is trying to measure is one familiar to him. Such concealment is certainly desirable initially, whatever magnitude is chosen; for one of the things he must be taught is that independent measurement requires no prior knowledge of the magnitude, except that it is the field of a transitive asymmetrical relation. But this does not entirely overcome the objections to choosing length or mass, or even electrical resistance. Even if it were possible to devise an experiment in which such magnitudes could be measured without disclosure of the operations being performed, it would probably be educationally desirable to make the disclosure at a later stage; and if this revealed something apparently silly, the lesson would be without effect.

Electric current *is* a suitable magnitude for the demonstration. It is easy to conceal the operations, for the operating elements are switches and the function of a switch is not disclosed by its exterior form. Further, even if the presence of switches suggests that the magnitude is current, the operations which they perform will not necessarily be guessed or be judged appropriate or inappropriate. For even a mature physicist, though he realizes at once, when his attention is drawn to the matter, that addition in branched circuits enables current to be measured independently, may not have known that fact consciously; the possibility does not seem to be generally regarded as common sense.

Let us make clear what is to be demonstrated. The proportions $1+1=2$, $1+2=3$, $\cdots$, are definitions of 2, 3, $\cdots$. By using them we can often (but not always) build up, from a given thing arbitrarily called 1, a "standard series," all different from one another and from the datum, to which the designations 2, 3, 4$\cdots$ must be assigned. The question whether here $2+2=4$, etc., is one of fact that cannot be predicted *a priori*, but must be established by experiment. If, but only if, $2+2=4$, the building up of the series leads to the kind of measurement useful in physics. (Of course it is not proposed to demonstrate this last statement; its proof requires a survey of all the uses of measurement.) In strictness, the trial should be carried further and the series extended so that the relations $2+3=5$, $2+4=3+3=6$, $\cdots$, are tested; and this should be pointed out to the student. But if he can be convinced of the significance of the $2+2=4$ test, the educational object will probably have been attained.

In the apparatus proposed (Fig. 1), A, B, C are three

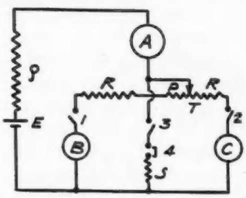

FIG. 1. Diagram of circuit.

ammeters with unmarked scales; E, ρ serve to vary the current through A (this current can be d.c. or a.c.). Contacts *1*, *2*, *3* are ganged in a multiple switch that has three positions: (i) *1* closed, *2* and *3* open; (ii) *2* closed, *1* and *3* open; (iii) *1*, *2*, *3* all closed. Contact *4* is controlled separately.

First, contact *4* is always open. Then the current through A in position (i) passes wholly through B; in (ii) passes wholly through C; in (iii) divides between B and C in a ratio determined by the setting T on the potentiometer P. The student designates some point on the scale of A as "1." In position (i) he brings the pointer of A to this mark by varying ρ and then marks a "1" on the scale of B at the position of its pointer. In position (ii) he similarly marks "1" on the scale of C. In position (iii) he varies ρ and T so that both B and C stand at "1"; he marks "2" the position of the pointer of A. In positions (i) and (ii) he marks "2" the corresponding positions on B and C. In position (iii) he varies ρ and T so that B stands at "1" and C at "2"; he marks "3" the position of A; and so on. He now, in position (iii), sets both B and C at "2" and notes whether A stands at "4." Owing to experimental error it will usually diverge slightly from "4"; he therefore repeats the whole experiment until he is convinced that, in the final test, A is as likely to stand on one side of "4" as on the other.

In the second half of the experiment, contact *4* is always closed. In positions (i) and (ii) all the current still passes through B or C; but in (iii) a fraction of it, depending on the setting of T, passes through the shunt S and through neither B nor C. He repeats the operations precisely as before; but now in the final test the mark on A stands consistently below "4" by an amount in excess of that which his previous observations have shown to be the experimental error. 2 and 2 do *not* make 4. Until he opens the apparatus, discovers what operations are performed by the switches and interprets his discovery in the light of knowledge that he could not have possessed when the problem of measuring current *first* occurred, the difference between the two results will be a mere empirical fact.

The theory of the second experiment (not reproduced here) shows that $5R$ is a suitable choice for the resistance S. The current and deflection of the pointer preferably should be differently related for each ammeter A, B, C, and for at least two of them should not be proportional; the more irregular the relation, the better. But an evenly divided scale of length may be provided, in order that the "marks" may be recorded in a notebook rather than on the instrument. For ease of operation, the current through A should be made almost independent of the setting of T—say, by making ρ large compared with R.

The apparatus can be used or readily adapted for two subsidiary demonstrations. One is the formation of submultiples of the unit. In principle this must be done by finding n things all equal whose sum is 1; but if n is (say) 10, the process is impossibly laborious without some guide. In practice this guide is usually derived from some algebraic law involving the magnitude and can logically be established only after the measurement of the magnitude is fully established. But in our example the necessary law suggests itself immediately from the operations already performed. From them, the intelligent student will have been led to suspect that if in position (iii) he halves the reading of A, he will halve also those of B and C. This suggests that he can obtain the mark "$\frac{1}{2}$" by setting A to "2," B and C each to "1" and then reducing A to "1" by changing ρ. An obvious procedure then leads to the mark "$1\frac{1}{2}$." He can now confirm the suggested law, and the correctness of the method of subdivision, by ascertaining in position (iii) that $1\frac{1}{2}+1\frac{1}{2}=3$.

In extreme cases independent measurement fails at the outset because $1+1$ turns out to be 1; that is to say, combinations of similar things are similar to the components. Such magnitudes are of great importance because they are "qualities," such as density. The possibility can be demonstrated by providing a fourth position (iv) of the multiple switch in which A, B, C are all in series. Having marked "1" on B and C in positions (i) and (ii), the student turns to (iv) and finds that, when B and C each read "1," A also reads "1"; no other numbers of the standard series can be established.—NORMAN CAMPBELL, *Proc. Phys. Soc.* (*London*) **55**, 98–102 (1943).

D. R.

Symposium on Technical Library Technics

(1) Time and effort may be saved and duplication of earlier work avoided if a thorough search of the literature precedes experimental work. Patents often result from such a study, even without laboratory research; they may thus be obtained more quickly and are more likely to be valid.

(2) The literature searcher must be on guard against errors, inaccuracies and obscurities in all publications. Indexes and abstracts must be used with care; the latter often omit important details.

(3) A good abstract must be clear and concise; it should give results rather than merely describe what information is contained in the original; it should include all significant details, such as special apparatus developed in the course of a project; it should be brief but unambiguous. A subject index should be an index of subjects, not of words; it must be accurate and complete.

(4) The librarian can be greatly helped in the choice of books by a committee consisting of the heads of departments or their designated representatives.

(5) The scientist, of all people, is under obligation to write not only so that he may be understood, but so that he *cannot be misunderstood*. Much of the difficulty with scientific literature lies not in the ideas but in the inability, or at least failure, to write clear, understandable English. Three factors contributing to the impairment of English speech are increasingly common: ignorance and unintelligence in the use of the hyphen; blind acceptance of new terms, without regard to their accuracy, meaning or necessity; omission of the ordinary connectives—prepositions and conjunctions.

The original articles should be consulted for details and for additional material on the preparation of manuscripts and the selection of technical books.—A. G. CONNOLLY, M. G. MELLON, E. J. CRANE, J. SASSO, E. PORTMAN, C. W. FOOTE and E. H. MCCLELLAND, *J. Chem. Ed.* **20**, 531–553 (1943).

J. D. E.

An Educational Decalog

It is the function of the educator to keep each individual busy in wholesome training at his highest natural level of successful achievement in order that he may be happy, successful and good. This sentiment is based on psychological theory and experiment and is revealed in the review of the progress in modern education. The goals implied in it are dominant as we approach the making of a blueprint for postwar education. For the sake of clarity, and to make my thought have horns, I make bold to name ten of the leading principles in education for freedom to learn.

1. *Recognize individual differences.* The principle of individual differences is a central theme of modern psychology and education in the classroom; but, strange to say, actual observance of it in teaching has remained largely like the gusts of wind about which we talk but do nothing. In college education, for example, there is a hang-over to the effect that where the Great Maker created all human beings different, it is the function of the teacher to make them all alike. An old-timer cornered with this accusation finds an alibi on the one hand in his theory of democracy and on the other hand in his inability to cope with mass education on the basis of recognition of individual differences. Both alibis are acknowledgment of inability to get out of a rut and lack of ingenuity for dealing with a critical situation at first hand.

2. *Make education student-centered.* In much of our instruction, the teacher not only decides what is worth learning but proceeds to cast the student's mind in the matrix of his own. Progress is rated in terms of receptivity. But there is now a dawning interest in a movement to return to the conception of the older universities in Europe, which were operated by the students who moved freely among institutions and chose what they should hear, see and do as a group and as individuals; higher education was

with them a sort of sport in which they vied in the mastery and elaboration of the thoughts of their day. The critical issue at stake is this: Is education a process of teaching or dominantly one of learning? If the former, it is teacher-centered; if the latter, student-centered. In the latter, the function of the teacher is to motivate and guide rather than to dole out the curricular diet.

3. *Build a basic, unified individual program.* Individual guidance of students at all levels will in the future replace much of our current classroom teaching. The student will spend more time in libraries and laboratories and will learn to read, observe and write at every stage from the primary to the graduate level. This plan calls for more educators and fewer drillmasters.

4. *Organize training for self-help in learning.* The school of hard knocks has frequently produced good results, yet we have taken the hard knocks out of education and substituted spoon-feeding of predigested food on a stream-lined transcontinental train. For instance, in the graduate school our best students do not need courses; what they need is to be thrown into the turbulent educational waters and learn to keep afloat and get somewhere.

5. *Make motivation the chief medium of instruction.* Motivation, perhaps the most highly respected term in current educational psychology, is based on the theory of activity as opposed to the theory of receptivity on the part of the student. Many students are self-motivated; they should not be interfered with in the process of mass education. Many students not so blessed can be motivated by an inspiring teacher. Some students enter higher education without the power of self-motivation or the capacity for being inspired; these should be sent where they may be taught love and respect for the use of their brawn. If the teacher has the power to motivate the student for the task of learning and gives him the necessary freedom, the student will work at his natural level of successful achievement. So I would say, the true educator is willing to let the principle of motivation play havoc with iron-clad curriculums, self-adulating lecturers, irritating quiz-masters and nut-picker examiners.

6. *Eliminate lockstep in assignment and promotion.* There is a natural process and rate of pure maturation aside from instruction that teachers should take into account. Yet the gifted student is often the retarded student; he is held back by the leash to the mediocre level and often has little for which to work.

7. *Integrate the school with community life and career.* American education began as a cloistered life. Today, for example, the profession of law has made marked progress in going effectively into the case-method of teaching as opposed to the supposed mental discipline of digesting Blackstone. The debater now debates living issues; the musician makes music function on the campus. How about the physiologist, the chemist, the historian, and so forth? Their trails into the education for life have not been effectively blazed. This is not to advocate the abandonment of fundamental training in organized disciplines; rather, the view here advocated is a device for the awakening of a new interest in the tools of learning and the revealing of the necessity of adequate background for a learned approach to any problem in school or out of school. What we need is to organize our training so that the student will deal with live issues very much from the same point of view that he will use when he enters upon a career.

8. *Make education continuous from cradle to grave.* Preschool and adult education are in the new order of the day.

9. *Be just in awarding praise and blame on the basis of capacity.* Praise and blame are the most powerful instruments in the motivation of learning and the formation of character. They are administered in the school in terms of credits, grades, and so forth, which are mere academic mechanisms. The praise and blame that count most in the formative period of life are the more or less unconscious expressions of attitude on the part of teachers and others whose judgment in our little world we regard most highly. As for grading systems and organized systems of promotion, such expression of praise and blame may be grossly unjust in that it places a premium on mediocrity. It is cruelly unjust to the person who has but one talent and is ruinous to the person who has five talents but is praised for paying out on two and a half or less.

10. *Aim to develop the individual in a well-rounded personality.* In the development of a rich, wholesome and effective personality, the intellect has been the favorite stock in trade; yet there is a wholesome growth toward development of the physical, moral, social, esthetic, religious and, may I say, philosophical selves. It is in the pursuit of these things that we should keep the individual busy in a wholesome training at his highest natural level of successful achievement in order that he may be happy, successful and good.—CARL E. SEASHORE, *Sch. and Soc.* **58**, 353–358 (1943). D. R.

Check List of Periodical Literature

The Kilgore bill. V. Bush, *Science* **98**, 571–577 (1943). A comprehensive discussion by the Director of OSRD of the exceedingly important and *separate* problems of the appropriate organization of science and technology for the prosecution of the war and of their organization in times of peace.

The return of the pulmotor as a "resuscitator": a back-step toward the death of thousands. Y. Henderson, *Science* **98**, 547–551 (1943). There is no valid scientific evidence for the claim that the "pulmotor" removes poisonous gases from the lungs and blood and induces a return of breathing in cases of partial drowning, electric shock and gas asphyxiation; yet it is again being exploited under the name "resuscitator," "with all the force of high-powered salesmanship and pseudo-science to the inevitable loss of many lives that could be . . . saved." Included in the article is some revealing information on "why doctors promote 'resuscitators.'"

Is teaching ability recognized? N. F. Stevens, *Science* **99**, 101 (1944). Apparently one source of the assertion so freely made that teaching ability is less adequately rewarded than, say, research ability is the failure of those who make it to recognize that teaching ability may be coupled with

other abilities. In other words, the mere fact that a faculty member is unable or unwilling to carry out a research program does not constitute *prima facie* evidence of teaching ability of a high order.

The significance and development of Hamilton's quaternions. H. T. H. Piaggio, *Nature* **152,** 553–555 (1943). Contrary to general opinion, E. T. Whittaker is inclined to think that "the development of relativity and quantum mechanics will sooner or later require quaternion methods for the more difficult problems . . . ; and that when the physicists have thus been forced to learn quaternions, they will use them for all purposes, and vector analysis will be forgotten."

Optical topics in part connected with Charles Parsons. Lord Rayleigh, *Nature* **152,** 676–682 (1943). Of particular interest is the discussion of lenseless telescopes and spectroscopes.

Influence of Newton's work on scientific thought. N. Teich, *Nature* **153,** 42–45 (1944). Emphasizes the social side.

Theories of trichromatic vision. H. Hartridge, Nature **153,** 45–46 (1944). A brief review of the advantages and disadvantages of the two rival hypotheses: (i) that each retinal cone is able to respond to red, green and blue; (ii) that there are three entirely different kinds of cone, one for each of the afore-mentioned sensations. The second hypothesis most closely fits in with the known facts.

The cyclotron. I. M. S. Livingston, *J. App. Phys.* **15,** 2–19 (1944). The first of two parts of a comprehensive article.

History of the measurement of heat. C. B. Boyer, *Sci. Mo.* **52,** 442–452, 546–554 (1943).

Cosmic rays. W. F. G. Swann, *J. Frank. Inst.* **236,** 521–540 (1943). A popular lecture.

The objectives of science in the secondary schools of the United States. G. W. Hunter and L. Spore, *Sch. Sci. and Math.* **43,** 633–647 (1943). A summary, based on replies from 655 schools, of 30 important objectives of science teaching, the methods used for achieving them, and the types of tests employed for evaluation.

Complacency in confusion. R. E. Doherty, *J. Eng. Ed.* **34,** 210–215 (1943). A helpful article addressed primarily to students.

Suggestions on how to study. H. P. Hammond, *J. Eng. Ed.* **34,** 216–222 (1943).

A synthesis of the results of twelve curricular studies in the field of science education. H. E. Wise, *Sci. Ed.* **27,** 67–76 (1943). Includes statements of the 100 physical principles found in the studies to rank highest in importance for purposes of general education. One conclusion is that, insofar as number of principles may be assumed to be a measure of relative importance of fields, the study of physics has greater value for general education than does the study of chemistry or geology.

Retirement at 65. P. Haensel, *Sch. and Soc.* **58,** 395–396 (1943). Only 16.6 percent of college professors are over 55 years of age, one of the lowest percentages of workers in various groups. A new scheme for retirement is proposed.

Experimental study of the tone quality of the Boehm clarinet. C. S. McGinnis, H. Hawkins and N. Sher, *J. Acous. Soc. Am.* **14,** 228–237 (1943).

Applications and limitations of mechanical-electrical analogies, new and old. J. Miles, *J. Acous. Soc. Am.* **14,** 183–192 (1943).

Symposium on color blindness. D. B. Judd, F. L. Dimmick and E. Murray, *J. Opt. Soc. Am.* **33,** 293–334 (1943).

Symposium on color in art education. D. B. Judd, N. C. Meier, D. R. Dohner, C. E. Foss, M. E. Bond, D. Nickerson, *J. Opt. Soc. Am.* **32,** 698–726 (1943).

New Address of Editorial Office

Professor Duane Roller, Editor of the *American Journal of Physics*, has resigned from Hunter College, New York City, to head the department of physics in Wabash College, Crawfordsville, Indiana. He assumed his new duties on March 1.

Professor Joseph D. Elder has also joined the physics staff at Wabash College, having resigned from Lynchburg College. In addition, he will occupy the newly created position of Assistant Editor of the *American Journal of Physics*.